ANALYSIS OF CREW PERFORMANCE

IN THE

APOLLO COMMAND MODULE

PHASE II - VOLUME I

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FOREWORD

The analyses presented in this report were performed by the Man-Machine Engineering Department of the Martin Company, Baltimore, Maryland, under Contract NAS9-5730 for the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. The program was technically monitored by Dr. Robert Jones of NASA.

This report presents the results obtained from Phase II of the program which was concerned with a comprehensive analysis of simulated Apollo Command Module performance data. Phase I of the study investigated the effects of mission and system design characteristics, while Phase II was directed more toward the relationship of performance with ancillary tools and measures, such as pilot checklists, biomedical status, and particular mission effects such as communication black-out periods.

The authors would like to express their appreciation for aid and assistance during the conduct of this phase to Dr. D. P. Woodward, R. J. Voorhies and L. Lewandowski.

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SUMMARY

The study reported herein and in Ref. 1 was performed in order to study the relationship between pilot performance and certain mission and system variables in the Apollo Command Module. The data were provided by five three-man crews who participated in the lunar landing simulations at the Martin Company, under NASA Contract No. NASw-1187 and NASw-833, Washington, D.C.

The Phase I effort (Ref. 1) analyzed each flight control, switching and guidance and navigation error as to its nature, magnitude, direction, and etiology. Specifically, the effects of performance on such variables as system design and operation, phase operation, systems operation within phases, display/control design, mission time, reaction time, and duty cycle arrangement were investigated using a variety of statistical techniques.

Results indicated that a geneally high level of performance was achieved and maintained. Certain isolated effects were demonstrated, such as increased switching variability over mission time, however, few other consistent trends were developed.

Phase II of the study, reported here, was concerned with certain additional system and mission performance variables, as well as the relationship between performance levels obtained and other system/mission variables, not studied in Phase I.

Specifically, the effects of the following variables were studied quantitatively:

(1) Checklists

(2) Communications blackout periods

(3) Control response to changing spacecraft inertia

(4) Isometric exercises

(5) Diurnal cycle variations

(6) Mission-to-baseline correlates.

Additionally, pilot comments were subjectively analyzed. Finally, the results of the present study and the Phase I study (Ref. 1) were evaluated for application to the current C/M configuration, mission, procedures, and training program.

Results, as in Phase I study, indicated a generally high level of performance on all types of tasks throughout the mission duration. Certain effects were observed, such as probably diurnal temperature and pulse rate variations, while the existence of other effects such as control response to changing spacecraft inertia was not precluded. The effects demonstrated in the control response analyses were confounded by other extraneous effects such as mission time. As in Phase I, few consistent trends were developed.

Further, it was possible to apply some of the results of this study to the current Apollo design and program. The more important extrapolations are listed below.

(1) The Apollo training program should include daily feedback of results.

(2) In order to provide maximum effectiveness in emergency manual control during Earth entry, a number of additional flight control parameters such as: range and altitude error and error rates should be provided. Such information displays should be located as close to the central line of sight as possible.

(3) Certain less critical switches and panels such as communications could be modified to reduce the probability of human error during periods of high stress.

(4) If system design requires pilot mission flight control performance which is close to the mean plus three sigma level exhibited during baseline, either additional training or system modifications may be required in order to reduce the probability of human error.

I. INTRODUCTION

This report will present the Phase II analyses results of a two-part study concerned with the evaluation of pilot performance data obtained in a ground-based simulation situation of the Apollo lunar landing mission. The analyses conducted in the total study were designed so as to obtain statistically verifiable information and factors which relate pertinent aspects of the operational situation to pilot performance. In order to accomplish the above goal, the pilot performance obtained in five lunar landing simulations were investigated relative to system design and mission parameters of the Apollo Command Module (CM). An additional goal of the program was to apply the obtained results to the operational CM in the following manner:

(1) Aid in the implementation of the CM display and control configuration.

(2) Aid in the provision of insight into the mission design in order to pinpoint error producing factors.

(3) Aid in the development of an astronaut training program.

(4) Aid in the provision of statistically verifiable data which could be used as an index of pilot performance reliability in the overall lunar landing mission.

As previously stated the data utilized in the present analyses were obtained from simulated missions. Previous analyses and data collected from simulated situations had indicated that by exercising judicious and careful experimental control, reasonable simulation fidelity, and by employing appropriate procedure, such data may indeed be useful for the accomplishment of the above stated goals. Further, because of the lack of a large number of operational systems and associated missions for this type of research analyses, simulation data appropriately utilized and coupled with the available operational experience and data are indeed a preferred and appropriate method.

The Phase I portion of this program previously reported was concerned with the comprehensive analysis of flight control, switching and navigation errors made by the crews during the five simulated missions (Ref. 1). The analysis was performed relative to the nature, magnitude, direction and etiology of the errors. The mission factors investigated, utilizing a variety of statistical techniques were:

(1) Systems effects

(2) Phase effects

(3) Phase by system interaction effects

(4) Display/control configuration effects

(5) Effects on pilot reaction time

(6) Mission time effects

(7) Duty cycle effects

(8) Biomedical effects.

The results of the analyses in Phase I indicated high performance was generally maintained by all pilots throughout the simulated mission. Further, the mission factors when analyzed yielded few consistent trends except for increased switching performance variability over mission time. The detailed conclusions are presented below.

A. The performance of the crews during the seven-day simulated missions appears to have been at an extremely high level in terms of reliability. The reliability measure was used because it easily related to the pilot to the other on-board systems and total mission effectiveness. Such factors as system effects, mission phase effects, and their interactions appear to contribute minimally in terms of any error trend in the obtained pilot performance.

B. An analysis of the simulator displays and controls indicated no general casual relationships between error performance and design. It was suggested that workload and the skill and training of the pilots, who participipted in the simulation contributed to the finding. It further was suggested that perhaps new human engineering criteria should be developed for this category of individuals in the spaceflight sitation.

C. An analysis performed on the criticality of the obtained errors indicated no critical switching errors but some critical flight control errors if a stringent performance criterion was used (e.g., mean +3 sigma criterion).

D. It appeared as a result of the analysis that mission time degraded performance in terms of variability of obtained performance rather than absolute changes in mean level of performance. The observed variability in performance during the simulated mission was not sufficient to affect mission success but it was noted that with increased workload, tasks which were more time critical, and extension of the mission duration, the variability might have increased to the extent of seriously degrading performance.

E. The total analysis indicated that with the workload level utilized in the simulated missions, the maintenance of a constant workload appeared to be more important than the absolute workload level at any specific phase. Further, the particular duty cycle utilized did not appear to affect the obtained performance.

F. No significant correlative trend was evidenced with any of the biomedical measures obtained during the simulation and the performance measures.

G. Since the performance measures taken covered a gamut of the behaviors involved and since the statistical sensitivity of the data was considered high and known for most task measures, it was stated that the obtained performance of the crews showed little degradation. However, such elements as workload, mission duration, etc. may be important had they been experimental variables.

The Phase II effort was directed toward additional mission parameters such as communications blackout effects, errors due to checklists, performance effects due to changing spacecraft inertia and correlations between mission and baseline performance. Additionally, the Phase II analyses included qualitative investigations of pilot comments and correlation of isometric exercise performance of any diurnal cycle effects on performance and biomedical status. However, prior to describing the details of Phase II, it may be well to review the method of obtaining the basic data.

The data bank available for performing the analyses as previously stated was the result of five, seven-day lunar landing simulations performed at the Martin Company (Ref. 2). The simulator facility included a high-fidelity, fixedbase Command Module Simulator (C/M), a Lunar Excursion Module simulator (LEM) gimballed in three degrees of attitude movement, a full-scale C/M translator capable of three degrees of translation movement, and associated out-the-window displays. Fifteen pilots were combined into five, 3-man crews. All of the pilots were graduates of the Air Research

Pilot School, Edwards Air Force Base, California, and were representative of the astronaut population. Each crew underwent five weeks of intensive training on all mission tasks, followed by a seven-day lunar landing simulation. The major differences between simulator and operational system tasks were:

(1) Manual implementation of certain tasks that are to be automatic in the operational system.

(2) Each flight control phase was repeated three times during the mission so that the performance measurement was possible for each crew member on each task. Otherwise, the Simulator Systems (Table 1) and phases (Table 2) were approximately the same as the operational C/M.

The simulation resulted in six types of reduced training, baseline, and/or mission data in addition to the new data. The reduced data are described below.

(1) Switching (switching performance reliability expressed as

$$1 - \frac{\text{Switching errors}}{\text{Switching operations}} \qquad \text{Eq. 1}$$

where an error was a missed or inadvertent switch operation).

(2) Flight Control (flight control performance reliability expressed as

$$1 - \frac{\text{Flight control errors}}{\text{Flight control parameters per phase}} \qquad \text{Eq. 2}$$

where a flight control error was defined as a parameter exceeding the mean plus three sigma value of that parameter obtained from the baseline data).

(3) Guidance and Navigation (guidance and navigation performance reliability expressed as

$$1 - \frac{\text{Errors}}{\text{Operations}} \qquad \text{Eq. 3}$$

where errors were defined as those values that exceeded the baseline errors value established by system calibration).

(4) Isometrics (Isometric performance expressed as "load displaced" on five exercises: knee, behind thigh, waist, shoulder, and overhead).

(5) Biomedical (Biomedical status expressed as: oral temperature, pulserate, diastolic and systolic blood pressure).

TABLE 1

BASIC SIMULATOR SYSTEMS

Basic Abbreviation	System
FC	Flight Control
SC	Stabilization and Control
GN	Guidance and Navigation
COM	Communications
ANT	Antenna
MS	Mission Sequence
ED	Emergency Detection
RC	Reaction Control
SP	Service Propulsion
CRY	Cryogenics
EC	Environmental Control
EP	Electrical Power
CW	Caution and Warning
L	Lighting

TABLE 2

MISSION PHASES

System Abbreviation	System
EPA	Earth Powered Ascent
TLI	Translunar Insertion
TRN	Transposition
IMU & MCC	Inertial Measuring Unit and Midcourse Correction
PD	Position Determination
LOI	Lunar Orbit Insertion
TEI	Transearth Insertion
EE	Earth Entry
SC	Systems Check

(6) Malfunction Detection (Malfunction detection performance expressed as

$$1 - \frac{\text{Switching errors}}{\text{Switching operations}} \qquad \text{Eq. 4}$$

in simulated situations.)

Figure 1 indicates the total number of data points c ollected during the simulation on Items 1, 2, 3 and 6 above. With the addition of Items 4 and 5, a total of 170,000 verifiable data points were collected. A more complete description of the simulator facilities and original program can be found in Refs. 1, 2, 3 and 4.

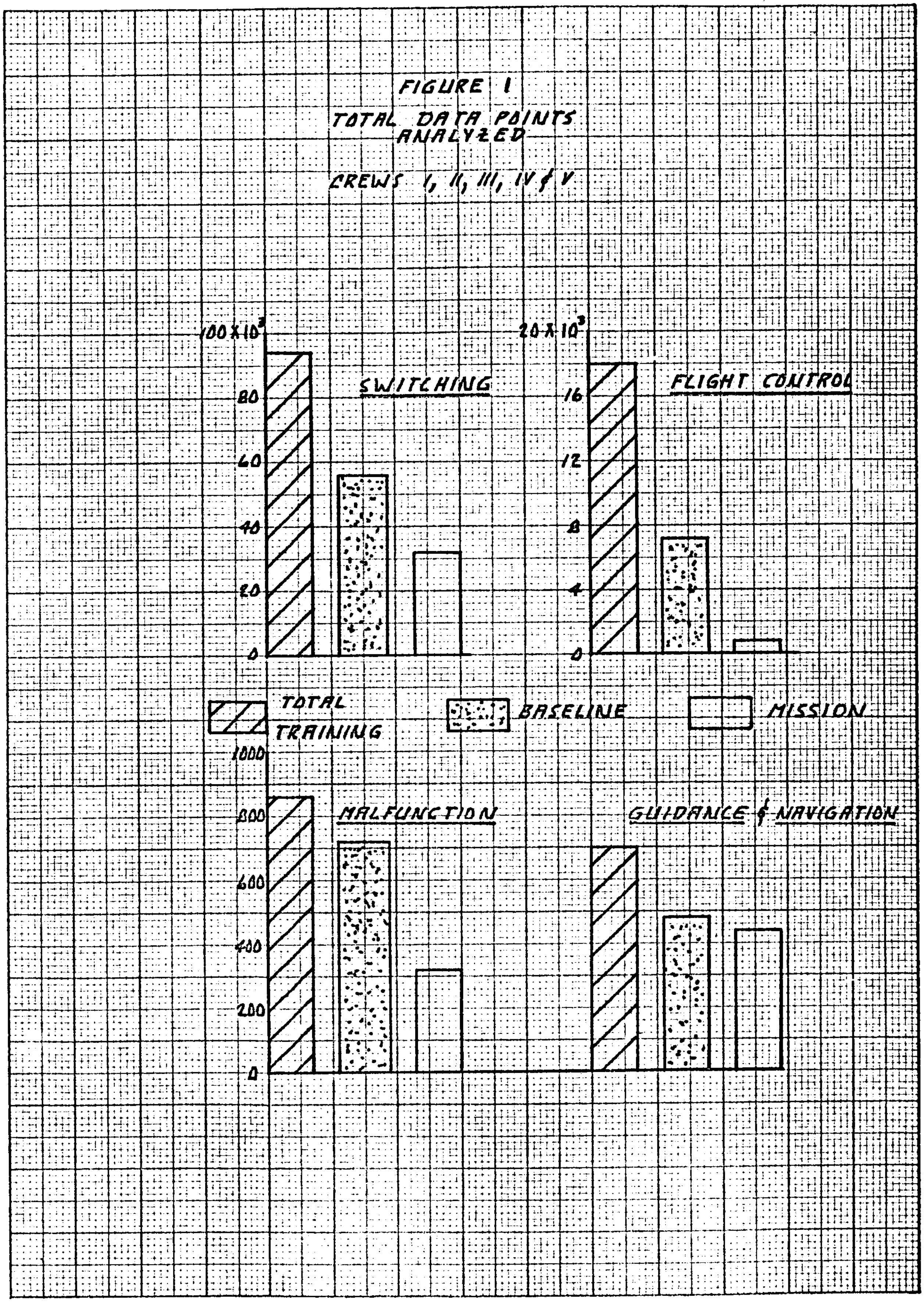


FIGURE 1
TOTAL DATA POINTS ANALYZED
CREWS I, II, III, IV & V
100 X 10^3
80
60
40
20
0
SWITCHING
20 X 10^3
16
12
8
4
0
FLIGHT CONTROL
TOTAL TRAINING
BASELINE
MISSION
1000
800
600
400
200
0
MALFUNCTION
GUIDANCE & NAVIGATION

The remaining chapters of this report will detail the analyses, results and conclusions of the Phase II effort. An additional Volume (II) provides supporting data.

II. DESCRIPTION OF PHASE II ANALYSES

As indicated in the Introduction, Phase II was concerned with an extensive qualitative, and where possible, quantitative analysis of relationships between the performance errors previously outlined in Phase I (Ref. 1) and the following:

(1) Pilot comments

(2) Checklist presentation

(3) Communications blackouts

(4) Changing spacecraft inertia

(5) Trends developed or additional investigations

(6) Mission-to-baseline correlation.

Additionally, the results of both Phase I and Phase II studies will be discussed in terms of the applicability to the Apollo C/M. This discussion will be directed toward recommendations for additions or modifications to the existing C/M design, training program, and operational mission.

1. Pilot Comments and Subjective Data Analysis

A. Review of Pilot Comments

Pilot comments were recorded during and after each simulated mission as written answers to a number of debriefing questions covering areas of general and specific interest. A typical set of debriefing questions may be found in Table 3.

TABLE 3

PILOT DEBRIEFING QUESTIONS

1. Did you experience any stress during the mission? If so, please describe in detail.
2. In general, how do you think your mission performance compared to your baseline (say, the last week or so of training)? In particular, were there any phases on which you felt that your performance was outstandingly different, either better or worse, from baseline?
3. Of the items mentioned in response to the above question, do you feel that you might have done the same thing (good or bad), in a typical training trial, or was there something peculiar to the mission that might account for the outstanding performance?
4. Do you feel that the recorded performance during the mission is indicative of your ability to perform during the mission? If you were to fly another such mission, say a month from now, how would your performance them compare to this mission's performance?
5. Was any of the mission performance affected by the training level achieved prior to the mission? That is, were there any phases on which you feel more training would have been desirable, in the light of your mission performance?
6. Please rank the flight controls tasks as to difficulty and justify the rankings.
7. Was the training program sufficient?
   a. Number trials
   b. Schedule
   c. Lectures
   d. Data Availability.

TABLE 3 (continued)

8. Discuss performance measure.

9. Discuss conduct of mission.

10. Discuss equipment performance.

11. Discuss mission food. Was it adequate?

    a. Diet

    b. Taste

    c. Texture

12. Discuss mission duty cycle. Was it adequate?

13. Were the functions assigned to the crew within your capability? What should be automated?

14. Discuss the C/M display panel. What changes do you recommend?

15. Discuss the LEM display panel. What changes do you recommend?

16. Was the physical conditioning program useful?

17. Discuss the dynamics of both simulators.

18. What value is this program to NASA?

19. What value is this program to the USAF? (And Navy)?

20. What value was this experience to you personally?

21. What recommendations do you have to improve this simulation and others of longer duration in the future?

These comments were analysed and categorized to pertinent mission/system factors such as phase, task, system, etc. Frequency of category occurrence was tabulated and compared with both performance and pilot opinion ratings established in Phase I (Ref. 1).

Secondary sources for pilot comments included notations in mission log books and tape recordings of mission events involving Crews III, IV and V. Prior to analyzing these comments, according to phase, category and frequency, a number of ground rules were established. These included:

(1) Separation of Comments by Crew Group - Comments for Crews I and II were grouped together and separated from those grouped for Crews III, IV and V. This was done not only to facilitate comparing the two separate sets of comments but also to accomplish the basic objective of comparing questionnaire responses obtained from Crews III, IV and V with their reported comments (questionnaires by which pilots rated the difficulty of flight control tasks and phases were only available for Crews III, IV and V). Additionally, the Phase I investigation had also indicated a statistically significant difference in mission switching performance between Crews I and II combined and Crews III, IV, and V combined (Ref. 1). Results of pilot opinion ratings based on questionnaire and their correlation with pilot performance are discussed and analyzed with relation to pilot comments in Section 2 below.

(2) Assignment of Categories to Pilot Comments - It appeared that several pilot comments could be properly assigned to more than one specific mission/system factor category. In such cases, the reviewers determined the most appropriate category for the comment in question, based upon their knowledge of the mission and system. For example, the following comment -- "Replace S-1 pressure gauges with green light because if pressure is not right, there's only one thing to do - abort." from the debriefing notes, may be considered either under a Display/Control or a System category. Because the pilot

in this case appeared to be more concerned with the appropriateness of system response indication, rather than the mechanics for displaying responses, it was decided to assign the comment to a "System" category.

(3) Comment Frequency - Comment on a specific item in each category and phase was enumerated on an individual pilot basis. That is, in no case was one pilot's comments on a particular item counted more than once in each category. However, if one pilot has stated almost identically the same words as another on a specific item, his comments were counted in the "frequency" tabulation, though not included under the descriptive "pilot comments" column in the table discussed below.

Presentation of pilot comments are presented in Table 4. Crews I and II comments are reported in Table 4A, while Crews III, IV and V comments appear in Table 4B.

B. Subjective Data Analysis

The preceding section provided the basis for a subjective comparison of recorded comments made by the pilots of Crews III, IV and V with results of their opinions questionnaire responses. A questionnaire was developed to obtain pilot opinion on the relative level of difficulty of flight control tasks performed during various mission phases (Ref. 1). Each phase, as a whole, was also rated on a scale ranging from "Very Easy" (to accomplish), to "Very Difficult" (to accomplish). The questionnaires were administered to each pilot during debriefing sessions following mission completion. (See Ref. 5 for a sample of the questionnaire used.)

TABLE 4

PILOT COMMENTS

KEY TO USAGE

Phase	-	Refers to that time-portion of the Command Module (C/M) mission in which specific operations or events occur. Phases are listed in Table 2.
Category	-	Refers to a general classification divided according to four basic areas of interest. Each area serves as a framework for more specific items of comment. The four basic areas are: "System" (including the entire C/M and its subsystems see Table 1); "Task" referring to a pilot operation performed or programmed for the simulated mission, or in training for that mission); "Display/Control" (consisting of the basic components by which the pilot switching or flight control tasks are performed during each separate phase); and "Environmental" Iincluding items separate from system operation which have some effect on the well-being and comfort of the pilots).
Specific Item	-	Refers to descriptors of one or more words which specify the man's subject or topic for a particular category's set of comments. For example, "food" and "sleep" are the main topics or items of interest for the "Environmental" category, whereas "simulator dynamics" and "communications" fall under the "System" category for all mission phases.
Frequency	-	Refers to the number of pilot comments recorded for a specific item of interest within a category. Only one comment per pilot on a particular area of interest was enumerated in that area. (Additional comments by the same pilot, or no comment on the item of interest by another pilot were not included in the totals.)

TABLE 4 (continued)

Pilot Comments - Refers to typical comments made by pilots on specific items of interest within categories and phases. Comments were made on specific flight phases, as well as on all phases in general.

Although comments are for the most part paraphrases of recorded remarks, they in some instances verbatim in order to substantiate, clarify or emphasize a particular point.

TABLE 4A - CREWS I and II

PHASE*	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS I-II)
EA	System	Indicator Change	1	Replace S-1 press. gauges with green light because if pressure is not right, there's only one thing to do - abort.
	Task Mode	Task Mode	2	Prefer to fly earth ascent manually (as crew has very little to do at this time).
TRN	Task	Lack of Data	1	There was no closing rate scale to tell how fast capsule is closing.
	Disp/Control	Gauge	1	Gauge used during TRN had too much parallax.
PD	System	G&N Equipment	4	Crew had G&N difficulty and had to throw switches in dark with one hand, holding checklist in other hand; very unrealistic star field; lack of sharp, clearly defined keel and background light in telescope prevented sighting of stars; CM needs larger viewfield in sextant; during navig. fix, moon ran completely off side.
	Task	Task Seq.	1	Perform IMU alignment phase prior to nav. fixes (IMU alignment much easier because little or no drift problem and no superposition of two bodies).
		Slack Time	2	More data-gathering tasks (other than just NF's and IMU's) should be performed during coast phases; there is not enough work to do during coast.
		Difficulty Estimate	1	Nav. fixes became taxing after making six in a row at half-hour intervals.
EE	Disp/Control	Roll Prog.	2	Response was too slow on initial part of the roll; causes a big range error.
		Indicator re-location	1	Since S-1 press. gauges are used only during 1st stage, put X, Y, Z indicator in their place (right in front of pilot).
		Displays	5	Displays considered poor, almost unsatisfactory; velocity and range gauges don't tell enough; scales are too large to be read down to where one wants to; H and H is hard to read; GV trace never worked even though 17 was not needed.

* See Table 2

TABLE 4A - CONTD

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS I-II)
All FLT. (No specific phase)	Task	"Fly-the-needle"	2	Tasks where it was necessary to fly-the-needle rather than toward the needle as a rule were the most difficult to learn; fly-to orientation in all instruments would be helpful.
	Disp/Control	Attitude & rate indicators	3	FDAI should have yaw angle coupling; using FDAI for insertions, if pilots off by more than 10 deg. in pitch, he doesn't have a good indication; cannot read calibration or markings within 3 deg.
All	System	Simulator Dynamics	3	Dynamics of system were very good; crew had to adapt it's responses to changing CM controls; controls are not coupled.
		Communications	4	Ought to be a volume control for the head-sets; eliminate headsets (caused discomfort) and develop a system whereby you could talk to control room (without them); questioned need for 3 radio valves - build one right in the center where everybody can reach it; an audible warning timer should be placed on board to let pilots know when events are coming up.
		On-board simulator	1	Cut out pilot and engineer radio panels and think about an onboard simulator capability.
		Realism	5	System should include more realism and stress situations (Addition of pressure suits, or helmets, would help); for achieving realism, crew could wear pressure suits, but for this simulation a shirtsleeve environment is a must; motivation and stress factors were largely missing on the mission; add out-the-window displays for CM (would add more realism); too much water carried on mission.
	System	Duty Cycle	3	Could not adjust to duty cycle (never got 4 hours sleep because of noise); there should be one 5-hour nap, every 24 hours at the same time; recommended sleeping for 6-hour periods).
	Task	Checklists	3	Checklist could be improved but is adequate now; checklist - needs a few minor changes (preferred notebook to cards even though it was slightly awkward); checklists are incomplete, not enough detail.
	Task	Training	6	Felt they were over-trained and that training was too long (with the exception of PT program); should not give same training weight to all tasks (i.e. systems check similar to earth entry); whould be mandatory to go through real-time mission far ahead of planned mission so you can use the data; training was excellent; TLI, TRN, and PD required minimum training time.

TABLE 4A - (CONTD)

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS I-II)
All	Disp/Control	Human Engineering	8	Many CM switches in wrong place; many which refer to entirely different systems look alike; some switches lack lettering and no correlation between one switch and the one next to it; no guarded switches or positive-throw switches (not even for critical functions); too much parallax in gauges; CM needs back panel and indirect lighting; CM was a poorly-designed cockpit layout.
	Environmental	Food	4	Too much volume and variety of food; food in general, too dry with poor taste; each pilot should pick his own menu; food might have given pilots headaches first few days of mission (and it took up too much space).
		Sleep	2	Sleep area needs soundproofing; need ear plugs to sleep.
		Comfort Control	2	Pilots should have direct control of temperature for comfort and realism.
		Psych. Factors	3	Motivation largely missing on mission; unable to adjust to living conditions; reliability "tailed off" towards end of mission because of boredom and complacency (along with some equipment malfunctions).
		Physical Conditioning	2	P.E. part of the training is the program's saving grace; all subjects sufficiently conditioned beforehand - there was no problem (on mission); physical conditioning was one of the best features of program.

TOTAL NO. OF COMMENTS--72

TABLE 4 - CREWS III, IV, AND V

PHASE*	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS III, IV, V)
EA	Task	Task Mode	4	Would like to run launch (and parking orbit insertion) manually; make earth ascent a manual function; prefer manual earth ascent over automated one; investigate putting pilot in booster loop.
	Disp/Control	Indicator Removal	1	Remove the 2 press. gauges for the S-1 booster and put someplace else (now it's right in front of pilot, yet is only looked at twice during EA)
INSERTIONS (TLI, LOI, TEI)	System	ΔV Cutoff Measure	5	ΔV cutoff performance measure is bad; if pilot sets ΔV on counter at a particular value, he can't be sure of exactly what analog will read (e.g. - pilot has 305 and analog measures 305.0 and 305.9); it doesn't mean much to plot the analog ΔV output as a measure of pilot performance - pilot ability to control and stop ΔV counter (at any target ΔV) is more meaningful; if you measure pilot performance, then measure what he sees - the counter, you're not measuring what the computer does-----; fidelity of readouts (ΔV cutoffs) not sufficiently accurate to justify nominal criteria; need to find good, reliable cue for ΔV cutoff.
	Task	ΔV Cutoff	1	Due to criticality of accuracy requirements in ΔV, this phase should be automated with pilot backup.
	Display/Cont	ΔV Cutoff	1	ΔV counter should have a tenths digit with different coloring background to assist in more accurate cutoffs on lower acceleration profiles.
TRN	Task	Lack of Data	2	Badly need closure rate indication ($\dot{X}$) for TRN task; X dot indication on TRN display would be useful.
		Difficulty Estimate	1	Maneuver could be easier with one rate meter ($\dot{X}$).
	Display/ Control	Indicator Location	2	Move TRN display down next to the "8-ball" (interpretation of TRN display easier in prime visual position); relocate transp/EE display down to where booster lights are.

*See Table 2

TABLE 4 - (Contd)

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS III, IV, V)
PD	System	G&N Equip.	3	G&N was somewhat confused; problems occurred in G&N system such as running entire sighting on sextant; make G&N system more reliable.
	Task	G&N Training	2	Few more lectures on G&N system (especially IMU alignment) would have helped in understanding what was exactly expected; need more on G&N system prior to first trial (MCC primarily)
EE	System	Lack of Data	1	Proper information not given, that is, control response is dependent on cue, and there is no indication of cue.
		Performance Parameters	5	Performance measures generally good, except for earth entry; better, more meaningful perf. parameters are needed during EE, including: dynamic pressure, gravity load, heat load, final crossrange, final range, and per cent of RCS fuel; during EE, display actual flight path and use a card or overlay for making error corrections or range-to-go; redesign roll control channel to permit normal piloting techniques in following roll programs.
	Task	Difficulty Estimate	8	EE is difficult because techniques are mechanical which defies consistent perf; EE difficult because you are given less information to go on; EE is most difficult phase since entire trial could be made or lost on 1st programmed roll; difficult because continuous decisions must be made throughout maneuver; EE most difficult CM task: it requires some sense of timing and judgment as to amount of correction to be used; EE was a task that required close attention to detail----Planning, foresight, and different flight profile according to errors made.
	Disp/Control	Roll Program	4	Roll needle guidance not easy to follow, lags pilot input too much; better roll prog. instrument needed (has too much slop); first roll of EE is 1/2 deflection and second roll is full deflection - they are supposed to be the same.
		Control Stick	1	Ship handles better with the S/M jettisoned.

TABLE 4? (CONTD)

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS III, IV, V)
ALL FLT. (NO SPEC. PHASE)	Task	Performance Parameters	4	RCS fuel used should be used as a perf. measure for all FC tasks; measure any axis which would yield a thrust vector while thrusting; time factors should be stressed more; add some displays (mission profile) and remove others (ΔE trace, etc.)
	Disp/Control	Attitude & Rate Indicators	8	Improve pitch and yaw presentations to reduce parallax; "swap" panels 4 and 7 (attitude ball and ΔV counter) to eliminate parallax on guidance needles; add sensitive rate meters on all three axes; damping factor in "3 ball" and stick hard to balance; put flight instruments in front of pilot's eyes; rate and attitude indicators should be made more sensitive and used to null down to zero rate.
		Control Stick	2	Rate stick does not act like a true rate stick (too sluggish slowing down); stick uneven in balance.
ALL	System	Simulator Dynamics	3	Felt that response of CM simulator was too sluggish with too much damping; control power should be higher; pitch and yaw loops could be tightened somewhat (but) overall dynamics are quite good; damping factor in all 3 rotational axes is excessive; dynamically simulator was excllent; CM dynamics appear adequate and realistic; simulator dynamics excellent for the study in progress; dynamics improved when S/M was separated.
		Communications	6	Eliminate requirement to wear headsets; provide command pilot with option of overhead speakers versus headsets; complained of "unnecessary confusion resulting relative to communication blackouts"; incorporate malfunctions in operating procedures to test Comm. system capabilities; Comm. system should have bell to wake up anyone who goes to sleep.
		Realism	1	Emergency procedures completely lack any sense of danger (they might be more meaningful if we were required to do them without a book --- and included time as a performance measure.

TABLE 4B. (CONTD)

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS III, IV, V)
ALL	System	Duty Cycle	9	Crew should have duty cycle 2 weeks prior to mission to become adjusted to it; well thought out schedule, but exercise should be run between sleep periods in order not to awake the man sleeping; not enough to do during on-duty time periods; duty cycle was good - too very little time to adjust to it (sleep period is perhaps too long); don't particularly care for the duty cycle (sleep periods far too short); duty cycle is pretty much optimum; duty cycle is adequate, well-planned.
	Task	Checklists	6	Improve checklist (good checklist should have critical items prominently marked, logical order of events, standard nomenclature, and should be easy to use); generally a poorly-arranged, non-professional item and needs standardization; errors partially caused by checklist ambiguities; fewer switching errors would be made with a better prepared checklist; improve checklists to make switching tasks realistic and meaningful; retype checklist to add certain improvements (e.g. - tape recorder procedures), and reproduce in "black on white" not "ditto" (hard to read).
		Training	9	Program generally outstanding (received everything we asked for one of the better training programs as far as flight control tasks are concerned; needed more lectures on mission itself; need to know where we are making mistakes during the first few trials; more error analysis and review during early training period would be of value; in some places the training (such as insertions) was overdone; too much emphasis on switching data training; crew should be allowed to experiment with tasks learned to see if they can find a better way to do them.
	Disp/Control	Human Engineering	9	Complete re-design of cockpit would be very helpful & necessary; put guards over any switch which could cause a critical system failure; install indirect lighting on all panels; separate Comm. switches on engineer's panel into tape recorder, S-Band, etc. sections (confusing to have all of them in 3 rows of switches with no separations between types); panel had switches that could be thrown inadvertently and no priority of importance assigned to switches; all dynamic

TABLE 4B - (CONT'D)

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS III, IV, V)
ALL	Disp/Control (Continued)			displays in front of pilot; more important switches should be guarded or of the lock type; color-code switches, arrange them in more specific groupings; change switch position labels; install adequate "night-lighting;" standardize "OFF" positions and have centering lines to facilitate more rapid cross checks; keyway bolts should be installed on all dump switches; eliminate parallax on guidance needles.
	Environmental	Food	9	Powder left very undesirable aftertaste; liquid is completely unsatisfactory, freeze-dry in general was very good; felt that crew performance was lowered because of the diet, particularly switching data; felt diet inadequate and recommended crew be put on proposed diet on an extended period (30 days prior to the mission); did not like the "powder"; don't believe this was the place to make a food evaluation... it did affect our performance somewhat; 2500 calorie diet was too much for people as inactive as we have been; freeze-dried food was excellent but powered food was terrible; improve quality of food.
		Sleep	5	Duty cycle sleep periods are far too short; schedule isometrics so as not to interrupt sleep of pilot sleeping; sleep area requires soundproofing; considered bunk fine for sleeping; poor sleep but good "rack" (too much noise).
		Comfort Control	8	Improve waste disposal techniques and location for washing (water sources located too high); relocate sink which is way off in top of corner; no ventilation in "head"; control cabin temp. from within spacecraft by thermostats; improve climate control (temperature) and ventilation systems in CM; add a ventilating exhaust fan in the latrine; Change seat design stressing comfort; harness is useless-----puts your position too far back from any of the consoles; replace power panel so engineer's seat and harness wouldn't be in the way so much.

TABLE 4B - (CONTD)

PHASE	CATEGORY	SPECIFIC ITEM	FREQ.	PILOT COMMENTS (CREWS III, IV, V)
ALL	Environmental	Psychological Factors	3	Stress caused by fatigue, diet, and day-to-day throwing of switches and standing duty, and food was detriment to morale; inadequate food intake led to generally poor feeling and irritability; had some stress during EE since desired to do task well.
		Physical Cond.	6	Physical conditioning program excellent (isometrics may have been overdone in some cases add timing for doing them was bad); schedule no isometrics in first waking hour (too weak and sleepy); pulled the chain excessively and at ridiculous times; diameter of isobar should be increased; program was very useful; IT program was real benefit to crew.

TOTAL NO. OF COMMENTS--134

Results obtained from the Pilot Opinion Rating questionnaires were scored numerically from low to high. Mean levels across pilots were calculated in order to obtain a rating value for each phase. Mission phase values were then ranked and correlated with flight control performance in terms of mission reliability by phase. Mean pilot rating for each C/M phase are indicated in Table 5 (Ref. 1). The higher scores indicate the "More Difficult" pilot ratings.

TABLE 5

MEAN PILOT RATING BY PHASE

Phase	Phase Mean
TLI	2.35
TRN	3.61
PD	2.23
MCC	2.26
LOI	2.22
TEI	2.63
EE	4.05

These values indicate an evaluation of greater difficulty by crew groups for Earth Entry and Transposition phases. It is also noteworthy that questions on the difficulty or confusion-provoking aspects of display location and interpretation had higher values for the TRN and EE phases in comparison to other C/M phases ranked (Ref. 2). In addition, questionnaire items on vehicle control difficulty, control/display relationships, and difficulty of maintaining required performance level received their highest level values for the EE and TRN phases.

Comments from Crews III, IV, and V, as shown in Table 4B, appear to support the above questionnaire results. A total of 41 comments were made on flight activities during specific mission phases, as follows:

EA =	5
TLI, LOI, TEI =	7
TRN =	5
PD =	5
EE =	19
Total	41

The 41 comments represent 30.5 per cent of the total 134 comments recorded in Table 4B for all phases, general and specific, regardless of category. Twenty-four (24) of the forty-one (41) comments (or about 60 per cent) pertain to items occurring during the Earth Entry and Transposition mission phases.

In addition to the greater frequency of comments found for the EE and TRN phases, inspection of the "pilot comments" column in Table 4B for these phases reveals that nearly all remarks are concerned with difficulties or problems encountered in system operation or task performance. The pilots generally recommended improved performance parameter presentation and display/control relationship identification.

The pilot comments data show close agreement with pilot opinion rating values, in that Earth Entry, and to a lesser extent, Transposition, were identified as mission phases having more difficult and confusing operations and tasks than any other phase.

It is noteworthy that Ref. 1 indicated no significant correlations between pilot oninion ratings and flight control performance. Furthermore, although it was demonstrated in the Phase I study that some crews performed better in some phases, there were, in fact, no consistent phase affects on flight control performance.

One of the reasons hypothesized for lack of significant pilot opinion performance correlation results or phase effects is that the investigation was based on flight control errors (those parameters beyond the mean plus 3 sigma baseline value). Since there were only 11 flight control errors recorded out of approximately 570 possibilities for error, it became very difficult to establish any trends on the basis of a statistical investigation. The reader is therefore referenced to Section II.4 of this report, which discusses "Control Response to Changing Spacecraft Inertia." For that analysis, raw flight control data were used and the results indicated that the EE phase exhibited significantly poorer performance than any other phase investigated. This result was demonstrated in baseline, mission, and normalized (by baseline) data. (TRN was not included in the analysis).

Thus, it can be argued that the pilot opinion ratings and comments were a valid index of relative phase difficulty, although performance efficiency (reliability) was not sufficiently variable to demonstrate any correlations.

2. Checklist Errors

In Phase I each switching and flight control error that occurred during the simulated mission was described along with its probable error etiology. The probable causes were summarized in tables for each crew, Crews I and II combined, Crews III, IV and V combined, and all crews combined. One of the categories of error etiology was "checklist" which referred to "those errors which may not have been committed if the checklist were more clear and detailed..... This category also includes the errors resulting from an inconsistent and indistinct checklist format."

None of the flight control errors were attributed to checklist deficiencies. The frequency of switching errors that were considered caused primarily by the checklist are indicated in Table 6.

TABLE 6

SWITCHING ERRORS ATTRIBUTABLE TO
PILOT CHECKLIST

	CREW COMBINATIONS		
	I & II	III, IV, V	ALL
Number of Checklist Errors	37	4	41
Total switching errors	222	19	241
Per cent of checklist errors	16.7	21.0	17.0

Although the percentage of errors for Crews III, IV and V combined is higher, it can also be noted that the total number of errors due to checklist are much higher for Crews I and II. One of the reasons for this is that the checklist was found to be incomplete on certain operations (notably the computer "UTEL" switch, "IFTS," and "Lamp Test" operations), following the second mission. As a result, the checklist was refined prior to its use by Crews III, IV, and V.

An analysis of switching errors indicated that the bulk of the Crews I and II errors considered a function of the checklist were mainly items that had been omitted from the checklist during various mission phases, whereas the checklist errors for Crews III, IV, and V were largely a function of throwing only one of two switches because the checklist was unclear as to number of operations.

It was decided that the checklist used by Crews III, IV and V should be examined in order to determine if any recommendations for the Apollo crew checklist could be developed. Only the C/M portion of the checklist was analyzed.

The checklist (illustrated in Ref. 5) was organized sequentially with the exception of certain mission phases and operations, which were included at the end of the C/M checklist. These operations, which were performed at various times throughout the mission, are listed below:

(1) Position determinations

(2) IMU and midcourse corrections

(3) System checks

(4) Tape record/play sequences.

Each mission phase noted in the checklist was rated by four individuals conversant with both the system and the checklist. This rating evaluation was made with the concept that the checklist was an operational tool rather than a training device. Thus, it was assumed that the user had a working knowledge of the system operation and did not require a complete set of detailed procedures.

The rating was on a three-point scale where 3 = good, 2 = fair, 1 = poor. The following criteria were rated:

(1) Component Identification - How well was the component(s) identified?

(2) Number of Operations - How well was the number of operations for each step identified?

(3) Operation Identification - How well was the step identified (e.g., "On" position)?

(4) Sequence - How well was the sequence of operational steps identified? This was only rated when sequence of operation was important.

(5) Response - How well was the system response to be monitored identified? This was only rated when a lamp was illuminated or a meter was read following a requisite switch operation (e.g., switch to Battery A and check to insure that meter is in green band).

Table 7 indicates the results of the checklist ratings.

TABLE 7

RESULTS OF CHECKLIST RATINGS

Rating		Component Identification	Number of Operations	Operation Identification	Sequence	Response Identification
(Good) 3	Freq.	621	595	601	60	109
	%	95.1	91	92	87	55.9
(Fair) 2	Freq.	22	40	33	3	26
	%	3.4	6.1	5.1	4.3	13.3
(Poor) 1	Freq.	10	19	19	6	60
	%	1.5	2.9	2.9	8.7	30.8
TOTAL		653	653	653		653

From the table it is evident that "Component," "Operation," and "Number of Operations" are fairly well identified in the checklist. The "sequence" category was not rated as high as the first three, mainly because several switches were originally printed out of sequence rather than reprint the checklist, and arrows were drawn to the appropirate position in the operational sequence. The "response" category was rated an order of magnitude lower than the first three categories. In most cases, this was caused by the lack of reference to the illumination of a push-button switch. That is, a switching operation which had a light associated with it would be identified, but the illumination action was not. However, a lamp of this sort only failed to illuminate in the simulation as a result of some malfunction. Since no malfunctions were programmed or occurred on any of the "illuminated" switches, there were no mission errors associted with the "response" category. For an operational system, the checklist should indicate that "Light A" should illuminate as a function of "Operation A." It is also noteworthy that critical switch operations were not identified in the checklist. This requirement was recognized by several of the pilots, however the criticality investigation performed in Phase I (Ref. 1) indicated that no critical switching errors were committed.

A second rating was performed on the checklist as a whole according to a five point scale where 5 = excellent, 4 = very good, 3 = good, 2 = fair, 1 = poor. The criteria and associated ratings are indicated in Table 8.

TABLE 8

RESULTS OF RATING OF TOTAL CHECKLIST

CATEGORY	RATING
a. Presentation (format, standardization, etc.)	2
b. Position identification (pilot, navigator or engineer)	4
c. Phase identification (e.g., Transposition)	4
d. Detail	2
e. Time treatment (mission-time indication)	2

Each of the categories are discussed below.

(a) Presentation - The checklist was found to have a large number of inconsistencies in format. This point was noted by nearly all the pilots. It is recommended that for an operational system a checklist should be standardized for all phases.

(b) Position Identification - In the margin, following each operation the appropriate position was denoted by a "P" (Pilot), "E" Engineer, or "N" (Navigator). This approach provided an unambiguous presentation of responsibility and sequence for an act.

(c) Phase Identification - At the top left corner of each page was an indication of the current phase. This permitted rapid reference to the appropriate set of pages for a particular phase.

(d) Detail - in general, detail was adequate, except for system checks. During this phase, which occurs eleven times in the mission, several operations are performed which are not described in sufficient detail. However, it is noteworthy that the phase investigation described in Ref. 1 did not indicate any poorer performance during system checks.

(e) Time Treatment - Mission time was treated inconsistently on the checklist. Since, during the operational mission, a crew member may only use the checklist for a quick reference, he must be able to acquire the appropriate step rapidly. When possible, mission times within a phase are the most appropriate way to do this.

The development and evaluation of a checklist is not directly spearable from the evaluation of a training program. It must be remembered that the checklist was used as a training aid, as well as an operational tool. One would expect that is a checklist is used solely as a mission aid and the training level is high, the importance of the checklist presentation is reduced. Conversely, if a mission is performed directly from a detailed checklist, its accuracy and presentation are much more critical.

The results of the error etiology investigation performed in Phase I (Ref. 1) indicated that Crews I and II had a combined percentage of mission errors due to the training of 35.1%, while Crews III, IV, and V had no errors attributable to training. Thus, it can be hypothesized that since Crews I and II were not trained to as high a performance level they reviewed the checklist more closely during the mission and were, therefore, less likely to make errors due to the checklist ambiguities. Crews III, IV and V, because of the higher level of training, used the checklist less often during the mission. This may explain why Crews I and II committed 15.7% checklist errors while Crews III, IV, and V committed 21.0% (Table 6).

However, as pointed out earlier, Crews III, IV, and V had a higher percentage of checklist-to-total errors than Crews I and II. The explanation for this is simply that the refinement of the checklist between Crews II and III was not as complete as the commensurate refinements that were applied to the training program. Thus, although the checklist was improved, the training program was improved to a greater extent.

Of pertinence to the operational C/M checklist are the following recommendations obtained from this analysis;

(a) The checklist should provide a clear, unambiguous presentation of operations in a standardized format.

(b) The operations should be time-referenced in the checklist for easy location.

(c) The critical tasks should be indicated in the checklist.

(d) The checklist should be sufficiently detailed to be used as a training tool, particularly in those phases which require a large number of switching operations, such as system checks. Thus, the pilot not only becomes familiar with the system, but, also with the checklist he is to use as an operational tool.

3. Communications Blackout Effects

During the Lunar Orbit phase, the C/M will pass behind the moon and voice contact will be lost. This condition was replicated in the lunar simulation. Additionally, all Crews sustained a simulated malfunction in voice communication of a six hour duration. Thus, 13.37 hours of each 168-hour mission were marked by an absence of voice contact. It was, therefore, of interest to determine if there were any deleterious effects on performance.

For Crews III, IV, or V, the following mission phases were performed during communication blackout periods; the number in parenthesis indicates the total number of repititions per crew.

(a) Lunar orbit insertions (3)

(b) Navigation fixes F1-F10 (10)

(c) IMU-MCC F1-F2 (2)

(d) Systems check No. 6 (1)

Since Crews I and II experienced the simulated communications malfunction during inactive periods there were insufficient data collected for individual crew analysis. However, analyses were performed on Crews I and II combined.

Because of the high rate of performance and extremely low variability of flight control data, flight control error measure was not subjected to this analysis (Ref. 2). This was also true of the guidance and navigation performance data.

The switching performance for phases (a) to (d) above was compared with four phases selected from the mission. Each of the selected phases listed below were from a different mission-time period, and were similar in task content to the blackout counterpart.

(a) LOI against TLI

(b) NF-F against NF-B

(c) IMU-MCC-F against IMU-MCC-6

(d) Systems Check No. 5 against Systems Check No. 6.

In order to preclude any effects resulting from varying phase difficulty, each mission phase reliability (R_M) was normalized by baseline reliability (R_B) for that phase using the formula:

$$R_N = R_M/R_B \qquad \text{Eq. 5}$$

Since low variability was also demonstrated for switching data, the nonparametric, Mann-Whitney "U" Test (Ref. 6) was selected. The results are indicated in Table 9.

TABLE 9

MANN-WHITNEY U TEST RESULTS:
COMMUNICATION BLACKOUT EFFECTS

Crew	U Value
III	5
IV	3
V	8
I-II	13
III-IV-V	7
All	4

No significant results

The data indicate that there were no significant differences in switching performance comparing the phases analyzed as a result of the communication blackouts.

As stated earlier, there was insufficient error occurrence to permit a comparison of flight control error data. In the following section, however, certain raw flight control scores were normalized and analyzed to study the effects of changing spacecraft inertia on control response. Each insertion was compared with the other two insertions. Since LOI was performed in the absence of ground communication, it was felt that an effect might be demonstrable with raw data, even though that effect might not be sufficient to cause a flight control error.

It can be seen from Table 16 that the normalized raw error scores are, indeed, higher for LOI than the other insertions. However, it is also noted that raw baseline scores were significantly higher during LOI (Table 12), with no apparent explanation, since the insertion flight tasks are nearly identical and communications were not interrupted during training. Therefore, these may be an effect on flight control performance due to communications blackout which is not sufficiently degrading to cause an error. This conclusion, however, is doubtful since the communications blackout periods had no apparent effects on mission switching performance, and the significant difference between LOI and the other insertions was also demonstrated in the baseline data (Table 12), where there was no communication blackout simulated.

4. Control Response to Changing Spacecraft Inertia

In its initial configuration at lift-off the Apollo vehicle will consist of four separate modules: the Saturn IV-B (SIV-B) Booster, Service Module (SM), Lunar Excursion Module (LEM), and Command Module (C/M). During various phases of the lunar mission, all of the above modules, except the C/M, are jettisoned. As the vehicle mass decreases, vehicle inertia is altered, thus altering the vehicle control response characteristics unless the thrust moment is latered appropriately.

The lunar landing simulation incorporated these inertia changes into the analog equations for C/M motion during the pertinent phases. This section shall describe the analyses performed to determine the effects of changes in control response on the obtained flight control performance.

A. Method

(1) Control Response Measurement

The change in control response characteristics was measured as the change in maximum angular acceleration available during the appropriate flight control phase, as derived from the equations of motion in the analog program for each phase. Figure 3 indicates the various phases in which the control response differs, the associated maximum angular accelerations, and the vehicle configurations.

One would expect that as long as control response is not excessively sensitive, increased maximum angular accelerations available would result in higher performance levels, since the spacecraft is easier to control with a given stick deflection. However, for this study this was not the case. During EE, the pilot was required to track a rapidly changing nominal roll needle. In order to perform this task, the pilot was forced to employ the attitude controller to its limit. This meant that the pilot had to make maximum use of the control response characteristics in order to make the requisite maneuvers, whereas only a small percentage of the maximum attitude control power available was required during the insertions.

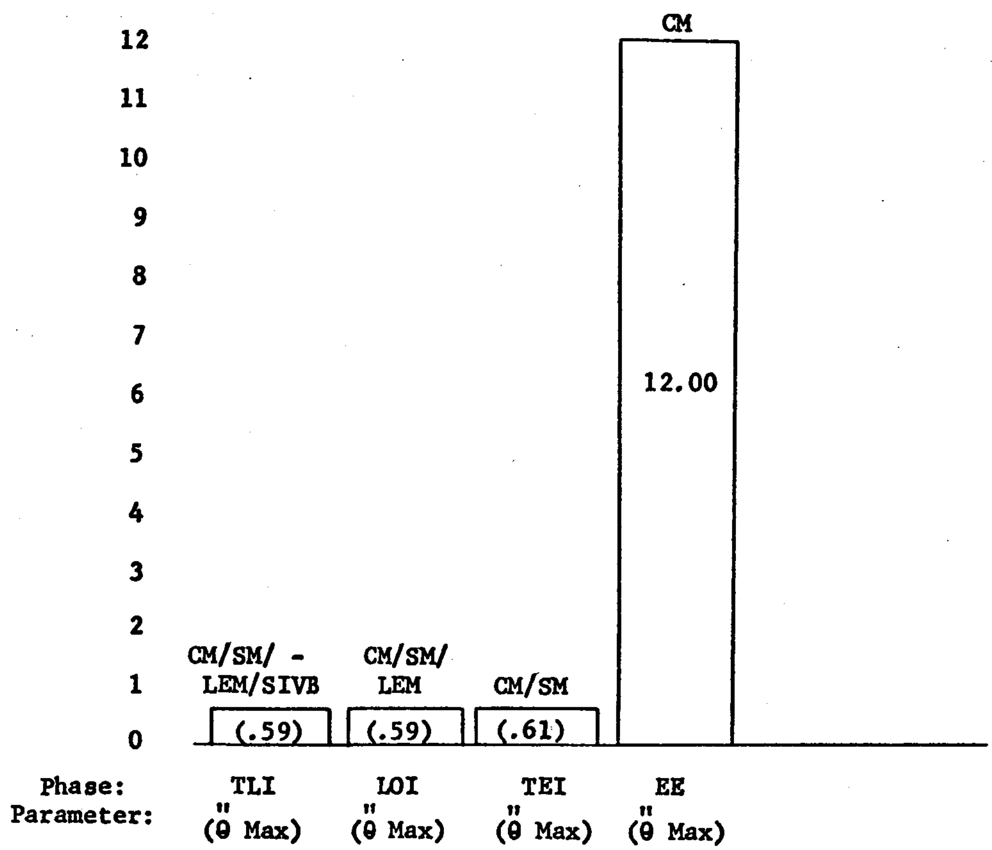
Thus, it was expected that pilot performance would be lower during EE and no difference would exist in error scores between the insertions. If differences between insertions were demonstrated as a function of changing inertia, it could be expected that TLI and LOI would have equal performance with TEI attitude errors differing from TLI and LOI.

(2) Pilot Performance Measure

Pilot crew score was used as the performance parameter and was measured in the following manner:

(a) For any given attitude control operation, the task was to obtain a particular attitude in the most "error-free" manner

FIG. 2. CHANGES IN SPACECRAFT INERTIA



KEY

CM	=	Command Module
SM	=	Service Module
LEM	=	Lunar Excursion Module
SIVB	=	Saturn IVB

by maintaining a "zero" attitude error indication on the appropriate display.

(b) Pilot performance was measured as an integrated deviation in raw score from the nominal over time as in Fig. 3.

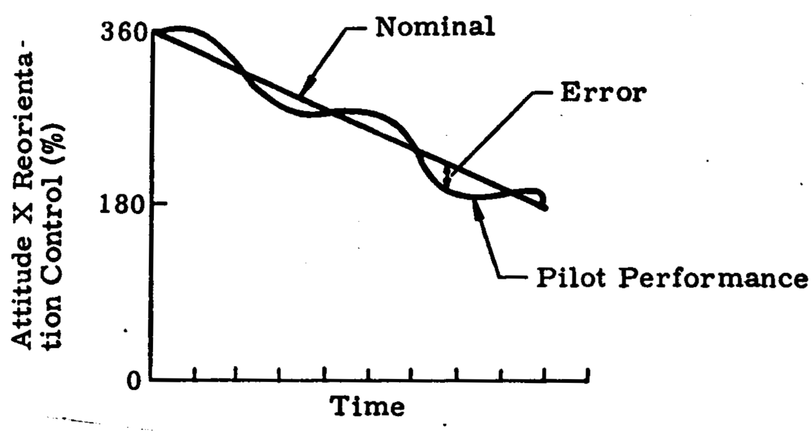


Fig. 3. Example of Derivation of Performance Parameters for Attitude Control

(c) For each attitude control for a phase, the continuous attitude errors are distributed with a mean of X_e average and a standard deviation of X_eSD where X represents the attitude axis being controlled.

Table 10 indicates the performance measures for each phase.

TABLE 10

MISSION TIMES, SPACECRAFT CHARACTERISTICS, FLIGHT CONTROL PHASES AND PARAMETERS CONSIDERED IN THE ANALYSIS OF SPACECRAFT INERTIA EFFECTS ON PERFORMANCE

Mission Time-Interval (hour)	Spacecraft Modules	Mission Flight Control (FC) Phase	Related FC Parameters
0-4:25	Command Service Module/Lunar Excursion Module/ SIV-B (CSM/LEM/SIV-B)	Trans Lunar Insertion (TLX)	--average pitch error (θ_e avg) --standard deviation of pitch error (θ_e SD)
4:25-74:05	CSM/LEM	Lunar Orbit Insertion (LOI)	--θ_e avg --θ_e SD
74:05-165:15	CSM	Transearth Insertion (TEI)	--θ_e avg --θ_e SD
165:15-168:00	CM	Earth Entry (EE)	--average roll error (ϕ_e avg) --standard deviation of roll error (ϕ_e SD)

Since raw scores were employed in the analysis, it should be pointed out that none of the parameters were beyond the flight control error criteria (mean plus 3 sigma) for any of the four phases analyzed. Consequently, only relative differences could be demonstrated between phases.

During the five weeks of intensive training, the various mission phases were randomized in order to control effects due to time, massed trials, fatigue, recall, etc. Since the control response for a given phase was identical for both training and mission, any differences in pilot performance should have been demonstrable with the baseline data as well as with mission data.

The first step, then, was to compare baseline data for phase differences. From Table 10, it can be seen that the measures for the Insertions are expressed in "pitch," whereas EE required a roll control, thus, the scores required standardization for comparison purposes. The baseline scores for all pilots were converted into a single standardized distribution using the statistic:

$$Z_i = \frac{X_i - \bar{X}}{S} \qquad \text{Eq. 6}$$

where:

Z_i = standard score

X_i = an individual score

$\bar{X}$ = mean score

S = standard deviation

The data were then subjected to t tests for each parameter (Ref. 7) which tested the relationships outlined in Table 11.

TABLE 11

TESTS PERFORMED FOR DIFFERENCES IN FLIGHT CONTROL PHASES WITH CHANGING SPACECRAFT INERTIA

	TLI	LOI	TEI	EE
TLI		t test	t test	t test
LOI			t test	t test
TEI				t test

As stated earlier, if control response had an effect on performance, one could hypothesize that the distribution of significant t values would be the same as in Fig. 2. This, however, would not constitute definitive proof since any differences might also be due to differences in task complexity, workload, displays, etc.

The next step was to treat the mission data in the same fashion as baseline with the expectation of similar results.

It was also necessary to analyze the mission data in terms of baseline performance levels. That is, if consistent significant differences occurred between the phases in both mission and baseline data, this would only be indicative of some difference in complexity between the phases, possibly confounded by extraneous factors such as mission time. If the mission data were normalized by the method:

$$\text{Normalized Performance} = \frac{\text{Mission Performance}}{\text{Baseline Performance}} \qquad \text{Eq. 7}$$

it might be possible to determine if any extraneous effects were contributing to any significant mission results developed. Two alternative results were possible:

(a) If differences between phases were developed with the normalized data, it would indicate that extraneous variables such as mission time, diurnal cycle, etc. had confounded any possible control response changes. This result would not preclude the existence of control response effects.

(b) If no differences were developed between phases for the normalized data, it could be concluded that phase performance levels obtained in the mission were similar to those obtained in baseline, and consistent significant differences were due entirely to differing complexities in phase tasks. One of the possible complexities could be a function of changes in control response characteristics.

B. Results

(1) Baseline Analysis

Tables 12 and 13 indicate the results of the baseline data analysis for the two sets of parameters.

TABLE 12

t TEST RESULTS, CONTROL RESPONSE EFFECT, AVERAGE ATTITUDE ERROR, BASELINE

	TLI	LOI	TEI	EE
TLI		-2.324*	-3.724**	.420
LOI			1.477	.603
TEI				.511

* Significant at .05 level

** Significant at .01 level

TABLE 13

t TEST RESULTS, CONTROL RESPONSE AFFECTS, ATTITUDE ERROR STANDARD DEVIATION, BASELINE

	TLI	LOI	TEI	EE
TLI		1.302	0	-137.82**
LOI			1.471	-172.853**
				-214.8**

*Significant at .05 level

**Significant at .01 level

As can be seen, there are significant differences between TLI and LOI, and TLI and TEI in average attitude error which is lowest in TLI. TLI and LOI have the same control response characteristics (see Fig. 3). Therefore, there is some other variable affecting LOI performance.

Table 13 indicates that EE was significantly different from the insertions in attitude error standard deviation. Since the difference between EE and the insertions in maximum attitude acceleration available is much greater than between the Insertions, the results might indeed be due to changing control response. However, the reader is referred to the discussion in the section on Method which indicated a fundamental difference between the maneuvers for EE and the Insertions. Thus, if the EE task is, indeed, more complex as the data suggest, one would expect this to be reflected in the attitude error standard deviation rather than in average attitude error. Since the significant t values are negative, the higher error scores were obtained in the EE phase.

(2) Mission Analysis

Tables 14 and 15 indicate the results of the mission data analysis.

TABLE 14

t TEST RESULTS, CONTROL RESPONSE AFFECTS, AVERAGE ATTITUDE ERROR, MISSION

	TLI	LOI	TEI	EE
TLI		-3.688**	-0.332	1.047
LOI			3.397**	1.115
TEI				1.055

*Significant at .05 level

**Significant at .01 level

TABLE 15

t TEST RESULTS, CONTROL RESPONSE AFFECTS, ATTITUDE ERROR STANDARD DEVIATION, MISSION

	TLI	LOI	TEI	EE
TLI		1.702	0	-14.349**
LOI			-.385	- 9.933**
TEI				-10.268**

*Significant at .05 level

**Significant at .01 level

Once again, the data indicate a significant difference between TLI and LOI in average attitude error. There is also a significant difference between LOI and TEI in average attitude error. As noted in Section I, TEI was the phase in which the pilots were apparently most aware of an adverse change in control response. The appropriate mission lag indicated that one crew perceived such a lag in the stick that they dismantled it to troubleshoot the problem. The lag indicates that the crew was convinced during the TEI that the control stick had malfunctioned. The data, however, indicate that for all missions combined, TEI demonstrated lower average attitude error than LOI. Thus, the pilots perceived a malfunction in the stick although the stick characteristics were unchanged from the training trials. The lower average attitude error obtained during the TEI phase may have been the result of the pilots perceiving the apparent stick lag and compensating for it. Thus, performance may have been enhanced by the pilots increased attention to the task.

It is hypothesized that the perceived excessive lag in control response was largely due to the recently completed lunar landing in the LEM which had vastly different dynamic characteristics. From Figure 3 it can be seen that the maximum attitude acceleration available in TEI was .59 deg/sec^2. The value for the same parameter in the LEM was 22 deg/sec^2 (Ref. 2). Thus, the LEM had a much more sensitive control response.

The results illustrated in Table 15 are identical to those for baseline for attitude error standard deviation although an order of magnitude lower. EE performance was significantly worse in attitude error standard deviation. Thus, the hypothesis of an effect due to changing control response cannot be rejected.

(3) Normalized Analysis

Tables 16 and 17 indicate the results of the analyses performed on mission data normalized by baseline levels.

TABLE 16

t TEST RESULTS, CONTROL RESPONSE EFFECTS, AVERAGE ATTITUDE ERROR, NORMALIZED

	TLI	LOI	TEI	EE
TLI		-3.361**	0.860	0.202
LOI			0.888	2.878**
TEI				-0.516

*Significant at .05 levels

** Significant at .01 level

TABLE 17

t TEST RESULTS, CONTROL RESPONSE EFFECTS, AVERAGE ATTITUDE ERROR, STANDARD DEVIATION, NORMALIZED

	TLI	LOI	TEI	EE
TLI		-0.181	-.031	-2.489*
LOI			+0.254	-3.294**
TEI				-4.276**

*Significant at .05 level

**Significant at .01 level

TLI was proven to contain significantly poorer performance than LOI in average attitude error. No logical reason for this is readily available. Both maneuvers are similar, and control response is identical. Also, average attitude error was significantly smaller for EE than LOI, suggesting that, when compared to baseline performance, mean pilot performance on EE was superior to LOI.

Table 17 indicates the same trend as in the baseline and mission data analyses. This suggests that there was some extraneous effect(s) on pilot performance, most likely, mission time. Section 6 of Phase I suggested a similar mission-time effect on switching performance variability, with inconclusive time effects demonstrated with flight control error data. Whatever extraneous variables may be, there is inconclusive evidence for rejecting the existence of a control response effect, since the baseline analysis indicates a difference in performance between phases.

C. Conclusions

The following conclusions can be drawn from the analyses described above:

(1) Some phenomenon had an apparent deleterious effect on LOI performance in average attitude error. In all three analyses, LOI performance was significantly worse than TLI, and in one case worse than TEI. No reason for this difference is apparent since there is no difference in tasks except for the magnitude of attitudes and imparted velocity and no difference in control response between LOI and TEI. One possible explanation is that crew workload is relatively light for approximately 64 hours prior to LOI preparation. This would support the conclusion of the Phase I Study (Ref. 1) that maintenance of a constant workload may be a more critical consideration than the minimization of workload. An alternative explanation might be that the anticipation of the LEM mission may have had a deleterious effect on LOI performance. However, the above conclusions are somewhat precluded by the significant differences evidenced in the baseline data analysis.

(2) Performance in EE was also consistently worse than other phases in all analyses of attitude error standard deviation. This initially suggests that the EE task was more difficult, but this does not explain the significant results developed from the normalized data. Some mission-time effects or anxiety at impending touchdown and an end to confinement might have had a deleterious effect on performance. But, since each of the phases falls roughly in succeeding mission-time quartiles, one would expect that a mission-

time effect would be demonstrable across the entire mission. This was not the case. If a mission-time effect does exist, it is expected that it would be commensurate with switching data time effects (Ref. 1) which indicated a significant difference between pre- and post-LEM performance.

3. The data are inconclusive concerning control response effect. The differences in attitude accelerations between TLI, LOI, and TEI are small enough so that a lack of significant results would not be surprising. Since the normalized data showed consistent significant differences between EE and all other phases, it must be concluded that some variable affected performance during that phase. If any control response effects did exist in EE, they were most certainly confounded by any other effects that may have been present, and the nature of the data is such that any separation of these effects is impossible.

In order to perform a study of control response effects using the integrated mission simulation technique, it would be necessary to replicate each flight control phase under different control characteristics. For example, TEI training trials could be performed using three different attitude control power settings. During the simulated missions each pilot would perform three TEI's, one under each control response condition. The nine condition/pilot test configurations would be randomized to prevent mass-trial effects. This experimental design runs the risk, however, of reduced face validity, with the possible consequence of reduced pilot motivation.

5. Data Trends and Additional Analyses

A. Isometric Performance

During the simulated mission, the pilots were required to perform a series of isometric exercises, using a specially designed device, in order to maintain muscle tonus in the confined space. Performance was measured as voltage traces on an oscillograph recorder, and converted into "load displaced." Five exercises were performed: knee, behind thigh, waist, shoulder, and over head. For purposes of this analysis, the knee, waist and, shoulder exercises were considered indicative of pilot performance over time as they represented the entire range of load displaced. Individual pilot performance is illustrated in Fig. 1 in Volume II of this report.

Original analyses of exercise performance are detailed in Ref. 2. A mission decrement was indicated as a result of these analyses. Pre-and post-mission exercise scores were generally higher than mission performance. This was attributed to such variables as reduced volume of the C/M, reduction of general activity level, requirement to perform late at night, etc.

The objective of the present analysis was to determine if there were any trends over time in isometric performance as opposed to:

(a) Switching performance

(b) Biomedical status (i.e., blood pressure, temperature, and pulse).

One possible application of such relationships is that pilot performance on an impending phase might be predictable from exercise performance if a consistent trend could be demonstrated.

Since very little mission performance variability in both flight control and navigation tasks was demonstrated (Ref. 2), no attempt was made to include these measures, as any correlations obtained with one variable constant are meaningless.

In order to arrive at a measure of isometric performance which was not biased by individual differences, it was necessary to standardize performance measures across all pilots. The pilots performed maximum strength tests prior to and subsequent to each mission. These scores were assumed to represent the relative strength of the pilots, and were averaged to provide a baseline level.

The baseline score for each exercise was divided into each mission score on that exercise, thus factoring out individual differences in strength.

Specified mission times were indicated in the (Ref. 8) for both exercise and biomedical data acquisition, but because of interferences with the work-rest cycle (e.g., the off-duty pilot was required to take biomedical data on the duty pilot, and he was frequently asleep) occasional lapses occurred, some as much as two hours.

In order to provide equal number of scores in each time interval, the data for all peformance measures (exercise, biomedical, switching) were arranged in 16-hour mission-time blocks. This provided a logical temporal breakdown, since the specified mission phase was divided into two intervals.

Exercise performance was then correlated with the other data for each crew individually, Crews I and II combined, Crews III, IV, and V combined, and all crews combined, using the Spearman Rank Order Correlation (Ref. 7). Figure 4 indicates the correlations performed. Standardized exercise scores were grouped over the mission-time blocks by use of the arithmetic mean.

The remainder of this section shall indicate the results of the two types of correlation analyses performed.

(1) Exercise by Switching Performance Comparison

Switching performance reliability was measured over each 16-hour mission-time period as indicated and corrdated with isometric performance for each crew individually, Crews I and II combined, Crews III, IV and V combined, and all crews combined.

The results of the correlation analysis appear in Table 18.

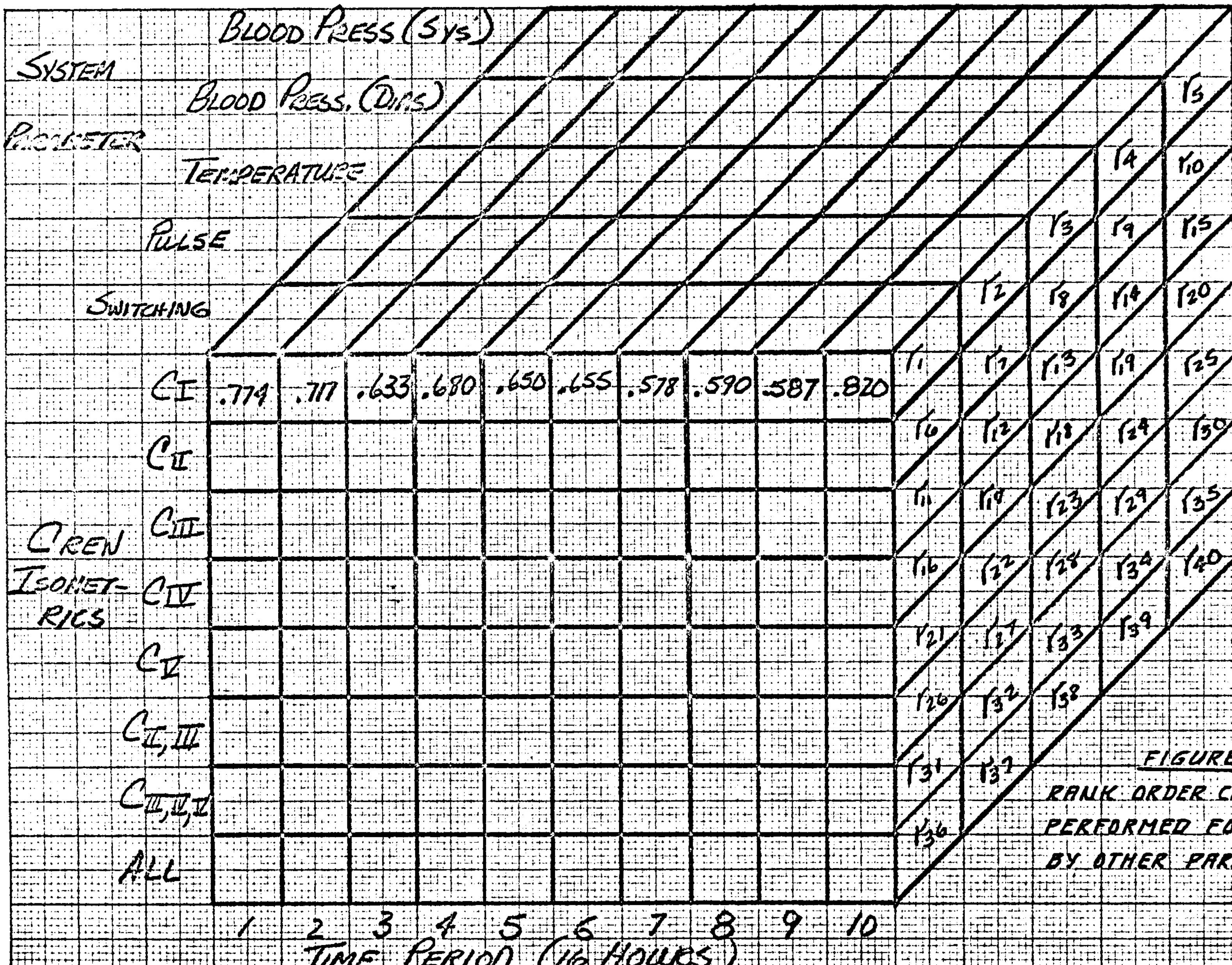


FIGURE 4

RANK ORDER CORRELATIONS PERFORMED FOR ISOMETRICS BY OTHER PARAMETERS

TABLE 18

Correlation Test Results, Standardized, Isometric
X Switching

Crew	s	
I	-0.127	+NT - No test
II	0.164	
III	-0.051	
IV	+0.479	
V	NT+	
I-II	-0.27	No significant correlations
II-IV-V	-0.24	
All	0.076	

Crew V was not tested since only three switching errors were committed during the mission.

As can be seen from Table 18, no significant correlations were developed between sitching performance and exercise performance.

(2) Exercise by Biomedical Performance Comparison - The mean of each four biomedical parameters was found for all pilots in a crew. Since, in general, the pilots had an equal number of measures in a given time interval, the arithmetic mean was considered a reasonable index of crew biomedical levels.

The results of the correlation analysis are plotted in Table 19.

TABLE 19

Correlation Test Results, Standardized Isometrix X Biomedical

Crew	Temperature	Pulse	Blood Pressure (Dias)	Blood Pressure (Sys)
I	No data	-.054	-.115	0.249
II	-.563	-.382	.297	.170
III	-.070	-0.394	-0.391	-.370
IV	.282	.479	.139	.312
V	-.269	-.818**	-.148	.542
I-II	-.318	-.100	-.473	.221
III-IV-V	-.054	-.254	-.727*	1.42
All	+0.248	0.139	-0.200	0.164

* Significant at the .05 level

** Significant at the .01 level

As can be seen from this table, only one result, Crew V exercise by diastolic blood pressare was significant at the.01 level, and only Crews III, IV, and V combined exercise by systolic blood pressure was significant at the .05 level. Thus, no consistent trend was demonstrated between exercise performance and biomedical status.

The analyses described above indicate no apparent relationships between exercise performance and other indices of mission performance or physiological levels. The isometric and biomedical performance levels are subjected to a diurnal variation analysis in the next section.

B. DIURNAL CYCLE

The duty cycle employed in the simulated missions was discussed in Ref. 1 and illustrated in Ref. 8. The essentials of this duty cycle were the following:

(1) Where possible, the duty period should not exceed 2 hr. However, an exception had to be made during the lunar landing phase.

(2) The sleep periods are 4 hr in duration for any one period.

(3) Two 4-hr sleep periods are provided every 24 to 26 hr.

(4) An off-duty period usually precedes and follows a sleep period to allow for acclimitization to sleep and awakening.

(5) Normally no more than 2 hr of off-duty occur during any period.

In general, the pilots were not provided any time prior to the mission to adapt to the duty cycle. In the operational system, long delays may be encountered prior to launch, thus precluding the allotment of time for duty-cycle adaptation. Thus, no adaptation time wasprovided in order to preserve operational fidelity

Considerable data are available in the literature concerning the effects of various work-rest cycles and day/night shifts on both physiological status and operator performance. Some investigations have suggested, for example, that a five day adaptation period is required before an invididual enters a new work-rest schedule (9). Others have stated that two to three months may be required before complete adaptation takes place (Ref. 10). Van Loon (Ref. 11) on the other hand, has found that adaptation of more than one week is useless if there is as much as one day reversal to a normal diurnal cycle.

It was of interest to determine if any of the measures collected were subject to any diurnal variation, and if so, how these variations compared to the literature. Biomedical, isometric, and switching data were categorized temporarily and subjected to statistical tests. The analyses are described in the following sections.

(1) Biomedical

As pointed out, during the lunar landing simulation study (Ref. 2) data were obtained on the physiological parameters of pulse rate, systolic and diastolic blood pressure, and oral temperature. The schedule called for each of these measures to be obtained at 8 hour intervals, plus or minus 1 hour.

The parameters were analyzed to determine the existence and nature of any variations across time intervals and whether any day-to-day adaptation occurred.

Before discussion the results, it should be pointed out that the pilots were well-trained, young, heathy individuals, and based on the minimal number of trends thus far developed, apparently under no appreciable stress during the mission.

(a) Six-hour Interval Variations

The biomedical data were analyzed for diurnal variations by plotting the data for each pilot against time. These plots are shown in Fig. 2 of the Appendix. Inspection of these curves indicate, in general, that there is somewhat of a cyclic nature in the physiological parameters measured. However, this is not consistent with each pilot through the mission, nor do all pilots show the same type of pattern. Normally one would expect to find the measures lowest in the morning hours and somewhat higher in the evening hours (Ref. 11). This does not seem to always be the case. One could argue that due to the work-rest cycle the diurnal cycle has been shifted, however, the available literature suggests that a shift would probably not occur at the beginning of the simulation, if at all during 7 days (Refs, 9, 10, 12), since the pilots were placed on the schedule a maximum of 2 days prior to the mission.

To further analyze the diurnal cycle it was decided to pool the data for each crew. The data were divided into four 6-hour time groups in the following manner: Group I - 0500 to 1100, Group II - 1100 to 1700, Group III - 1700 to 2300, and Group IV - 2300 to 0500. The two periods between 1100 and 2300 were taken as PM measures with the other two periods taken as AM measures. The gross time effect on the biomedical measures was determined by comparing the four intervals as follows: I-II, I-III, I-IV, II-III, II-IV, and III-IV. The null hypothesis required equal mean levels for a given biomedical measure for each time interval compared, $X_1 = X_2$. The test selected was a t-test (Ref. 7) to evaluate the significance of the difference between interval means. The analysis was performed for each biomedical measurement, the results are shown in Table 20. It can be seen that of the 120 comparisons made, only 27 show significance at either the 0.05 or 0.01 level. Of these 27 significant comparisons, 7 were from the pulse rate data, 3 from the diastolic blood pressure, 5 from the systolic blood pressure, and 12 from the oral temperature data. It is further seen that 17 of the significant values are related to the 2300-0500 time period.

The analysis described above was also performed on the pooled data for all crews and is indicatedin Table 21. Here it is seen that there are 6 significant values out of 24 comparisons. All of which are related to the 2300 to 0500 time period. As in the analysis by individual crews, the majority of the significant values are related to oral temperature and pulse rate.

TABLE 20

t Test Results - Biomedical, Diurnal Cycle, Individual Crews

CREW I - TIME CATEGORY

	I-II	I-III	I-IV	II-III	II-IV	III-IV
Temperature	.260	1.04	4.40**	.45	1.46	.35
Pulse	0.01	0.22	0.32	0.53	-0.007	-0.53
BP(D)	.40	.10	.96	.22	.85	.57
BP(S)	.09	1.06	1.72	.74	1.24	.46

CREW II - TIME CATEGORY

Temperature	8.46**	-3.25**	2.32*	.4	3.21**	3.61**
Pulse	-.67	-.36	1.32	.55	2.46*	2.39*
BP(D)	.40	-.39	.53	-.73	.18	.79
BP(S)	.54	-.62	-.25	-1.08	-.69	.27

CREW III - TIME CATEGORY

Temperature	-1.07	1.31	0.73	-0.08	1.80	2.33**
Pulse	-0.48	-1.67	0.65	0.94	1.31	2.89**
BP(DIAS)	-1.19	-0.65	0.08	0.51	0.97	0.84
BP(SYS)	-1.54	0.93	0.37	0.99	2.39*	1.60

*Significant at .05 level

**Significant at .01 level

TABLE 20 (continued)

CREW IV- TIME CATEGORY

	I-II	I-III	I-IV	II-III	II-IV	III-IV
Temperature	-3.00**	-3.67**	0.00	-1.07	1.95	2.75**
Pulse	-1.05	-0.25	1.29	0.81	2.16*	1.63
BP (DIAS)	0.21	1.07	0.94	0.73	0.59	-0.004
BP (SYS)	0.70	0.68	1.46	-0.04	1.02	1.13

CREW V - TIME CATEGORY

	I-II	I-III	I-IV	II-III	II-IV	III-IV
Temperature	-1.52	-0.30	1.25	-0.25	2.60*	4.67**
Pulse	-3.13**	-1.35	1.47	1.59	3.90**	2.89**
BP (DIAS)	2.27*	-0.60	0.60	-3.96**	-2.42*	1.63
BP (SYS)	2.55*	0.10	2.74*	-3.41**	-0.20	3.61**

*Significant at .05 level
**Significant at .01 level

TABLE 21

t-Test Results, Biomedical Diurnal Cycle, All Crews

	I-II	I-III	I-IV	II-III	II-IV	III-IV
Temperature	-1.15	-1.91	2.00*	-.055	2.79**	3.75**
Pulse	-.71	-.28	1.59	1.08	2.61**	3.52**
BP(D)	.61	.86	1.79	.19	1.06	1.00
BP(S)	1.13	1.33	2.26*	.03	1.11	1.23

*Significant at .05 level
**Significant at .01 level

While no firm conclusions can be drawn from the above there is some indication that the diurnal cycle is being maintained with the low point occurring in the early morning hours. However, it is impossible to determine when the high point of the cycle occurs.

The above data are largely consistent with the available literature. For example, Lewis and Lobbon (Ref. 13) have pointed out that some physiological parameters are susceptible to environmental changes while others apparently demonstrate an intrinsic periodicity. Of the parameters that were studied, body temperature was the single measure most effected by abnormal time routines, with the low points occuring in the early morning. Van Loon (Ref. 11) has developed similar results.

Most of the physiological data available in the literature was collected in two-hour intervals, whereas, as indicated, this study required measures to be taken every eight hours. In order to conclusively establish the existence of any diurnal cycle effect, biomedical measures should be taken more frequently. This is generally the case for both other studies of duty cycle effects as well as the operational Apollo mission.

(b) Mission Duration Effects on Biomedical Performance

Each of the mission-time intervals discussed in the preceding section were analyzed for any apparent changes over the entire mission duration. Since certain diurnal effects had been indicated, it was of interest to determine if any adjustments to the work-rest cycle had occurred, such as demonstrated by Lewis and Lobban (Ref. 13).

To investigate this possibility, mean levels for each biomedical parameter for a given 6-hour time interval (e.g., 0500-1100) were found for each of the seven mission days for all crews.

To test for daily differences, a t-test (Ref. 7) was performed which tested differencesbetween day 2 and day 7 on each biomedical parameter. The results are presented in Table 22.

TABLE 22

t-Test Results, Daily Difference in Biomedical Status Within Time Intervals, All Crews

		Parameter				
		Pulse	BP(D)	BP(S)	Temperature	
Time Period	0500-1100	.66	.89	1.01	-2.69	
	1100-1700	2.00	.48	-.499	.204	No significant results
	1700-2300	.29	.61	.42	-.38	
	2300-0500	.60	-1.20	.52	.14	

As can be seen, there were no significant results, thus there was no apparent shift in the diurnal cycle. These resits agree with the findings of Alluisi et al (Ref. 9).

(2) Isometric

(a) Eight-hour Interval Variations

Isometric performance was discussed in Section 5.A of this report. Since isometrics were performed approximately every 8 hours during the mission, it was decided to determine if any diurnal effects could be demonstrated.

The standardized isometric performance (see Section 5.A) on two exercises, knee and overhead, was separated into three 8-hour intervals and t-tests similar to those discussed for biomedical data were performed. The two exercises represented the extremes in "load displaced." The results are indicated in Table 23.

TABLE 23

t-Test for Diurnal Cycle Effects of Isometric Performance

Crew	I-II Knee	I-II O.H.	I-III Knee	I-III O.H.	II-III Knee	II-III O.H.	
I	.842	-3.65	1.224	.659	-.267	1.146	
II	-1.2	-.804	-.415	-.560	-.323	.281	
III	.121	1.403	.383	1.157	.298	-.346	No significant results
IV	.554	.235	1.181	-.525	.684	.167	
V	2.437	-.042	2.409	1.126	.201	2.413	
All	.42	.102	.43	.668	.089	.761	

I = 0900-1700
II = 1700-0100
III = 0100-0900

No significant results were demonstrated, thus obviating any diurnal cyclic effects on isometric exercise performance.

(b) Daily Variations in Isometric Exercise Performance

Normalized performance for three exercises, knee, waist, and shoulder, was analyzed for daily differemes within time intervals across the mission in the same way as biomedical status. For this test, data from day 2 of the mission was compared with the data collected on the final day on which complete exercise data was available. This was either day 5 or day 6 in all cases. The results of the t-tests are indicated in Table 24.

TABLE 24

t-Test Results, Daily Differences in Isometric Exercise Performance Within Time Intervals, All Crews

Time Internal	Exercise Knee	Exercise Waist	Exercise O.H.	
0900-1700	-1.049	.546	1.184	No significant results
1700-0100	1.286	-.855	1.952	
0100-0900	-1.661	-.955	-.617	

As with the biomedical data, no significant results were obtained, suggesting that performance within given 8-hour time intervals remained constant across the mission.

(3) Switching

It was also of interest to determine if any diurnal cycle effects could be demonstrated for the switching performance for each eight-hour mission time interval. Figure 5 indicates the pre- and post-LEM switching performance by eight-hour interval for all crews combined. As in Phase I, (Ref. 1), the effect over mission performance is apparent, although performance reliability is consistently high. The reliabilities of Crews I and II combined, Crews III, IV, and V combined and all crews combined are indicated in Table 25, 26 and 27.

The eight-hour time intervals were tested against each other for diurnal cycle effects. Because of the lack of variability in the switching data, the nonparametric Mann-Whitney U Test (Ref. 6) was employed. The results are indicated in Table 28.

TABLE 28

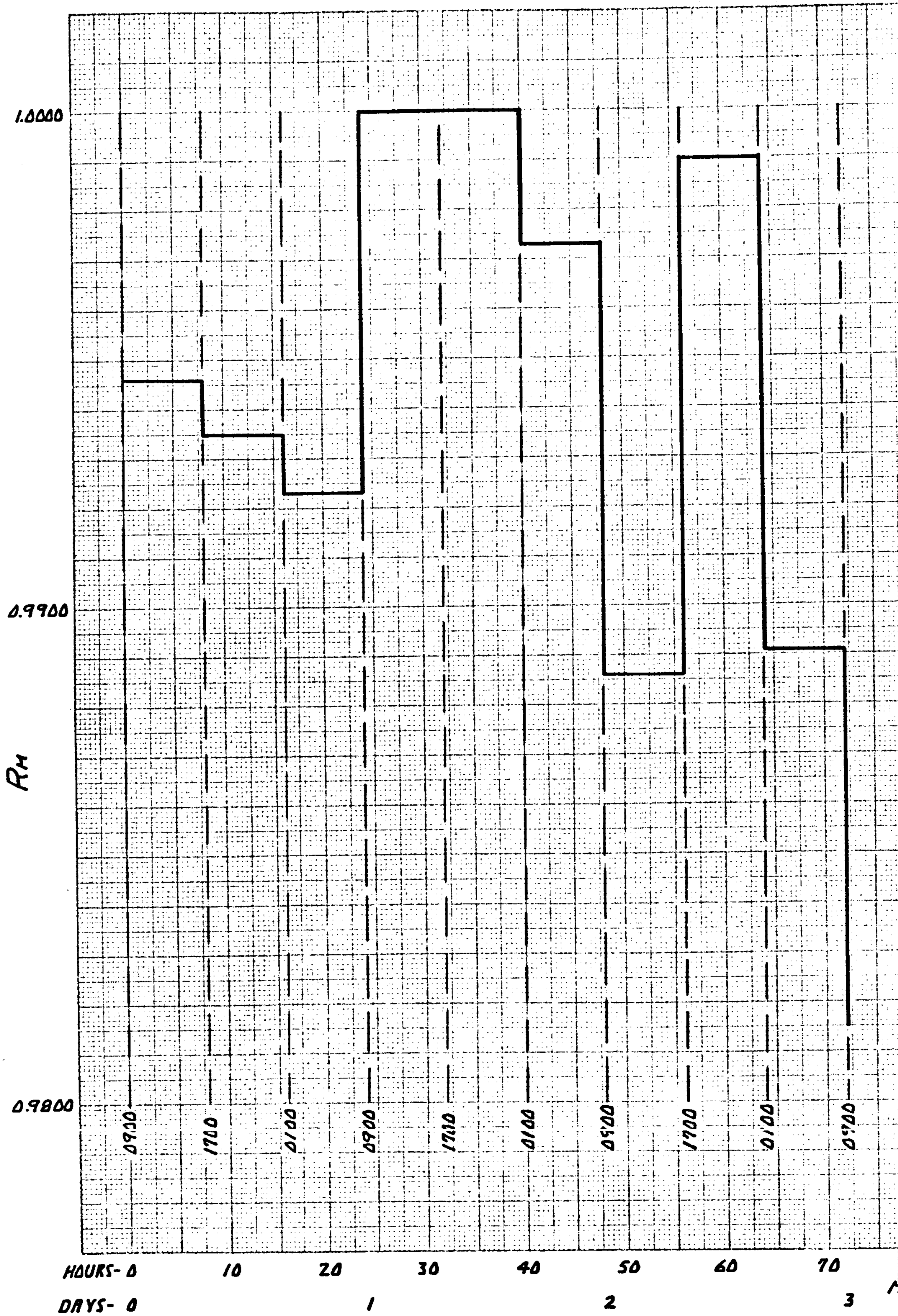
Mann-Whitney U Values for Diurnal Cycle Effect on Mission Switching Performance

	Time Interval			
	I-II	I-III	III-IV	
Crews I, II	13	19	10	
Crews III, IV, V	9	16	18	No significant Results
All Crews	13	18	12	

I = 0900-1700 mission time
II = 1700-0100 mission time
III = 0100-0900 mission time

As indicated, no significant results occurred, thus there was no apparent effect on switching performance due to diurnal cycle.

62A-1


1.0000
0.9900
0.9800
RM
0900
1700
0100
0900
1700
0100
0900
1700
0100
0900
HOURS- 0
10
20
30
40
50
60
70
DAYS- 0
1
2
3

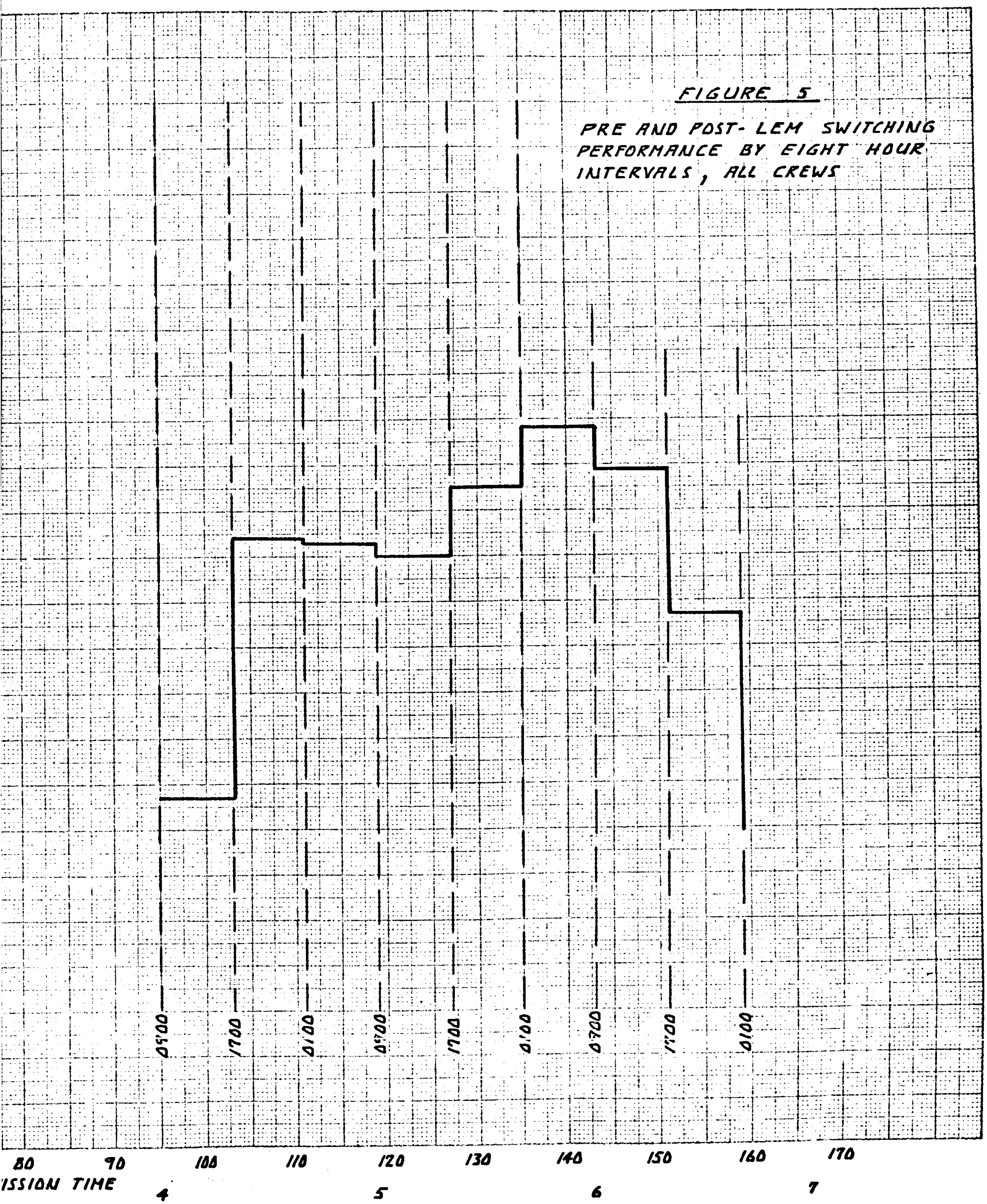


FIGURE 5
PRE AND POST-LEM SWITCHING PERFORMANCE BY EIGHT HOUR INTERVALS, ALL CREWS
0900
1700
0100
0900
1700
0100
0900
1700
0100
80
90
100
110
120
130
140
150
160
170
ISSION TIME
4
5
6
7

TIME INTERVAL 0900 – 1700		TIME INTERVAL 1700 – 0100		TIME INTERVAL 0100 – 0900	
DAY	REL.	DAY	REL.	DAY	REL.
1	0.9896	1	0.9845	1	0.9813
2	1.0000	2	1.0000	2	0.9928
3	0.9705	3	0.9973	3	0.9720
4	0.9494	4	LEM	4	LEM
5	0.9508	5	0.9774	5	0.9438
6	0.9045	6	0.9858	6	0.9893
7	0.9223	7	0.9769	7	0.9625

TABLE 25
EIGHT HOUR INTERVAL
SWITCHING RELIABILITIES
CREWS I & II

TIME INTERVAL 0900 — 1700		TIME INTERVAL 1700 — 0100		TIME INTERVAL 0100 — 0900	
DAY	REL.	DAY	REL.	DAY	REL.
1	0.9973	1	0.9986	1	0.9991
2	1.0000	2	1.0000	2	1.0000
3	1.0000	3	1.0000	3	1.0000
4	0.9978	4	LEM	4	LEM
5	1.0000	5	0.9979	5	1.0000
6	0.9959	6	1.0000	6	0.9957
7	0.9978	7	0.9982	7	0.9972

TABLE 26

EIGHT HOUR INTERVAL

SWITCHING RELIABILITIES

CREWS III, IV & V

TIME INTERVAL 0900 - 1700		TIME INTERVAL 1700 - 0100		TIME INTERVAL 0100 - 0900	
DAY	REL.	DAY	REL.	DAY	REL.
1	0.9946	1	0.9935	1	0.9923
2	1.0000	2	1.0000	2	0.9973
3	0.9886	3	0.9990	3	0.9891
4	0.9815	4	LEM	4	LEM
5	0.9847	5	0.9904	5	0.9903
6	0.9900	6	0.9915	6	0.9928
7	0.9919	7	0.9887	7	0.9839

TABLE 27

EIGHT HOUR INTERVAL

SWITCHING RELIABILITIES

ALL CREWS

The findings of Alluisi et al (Ref. 9) indicated that crews can be effective for periods of two to three weeks on a 4-hour on, 2-hour off schedule, and effectiveness can be maintained for two to three months on a 4-hour on, 4-hour off schedule. Thus, although the duty cycle employed during this study was different than that studied in Ref. 9, it is felt that the Alluisi data represent a more stringent work-rest cycle, and that the simulator data agree with the finding that individuals can function effectively over set periods of time, under adverse routines.

Figure 6 indicates that switching errors were distributed proportionally to total operations over each eight-hour time interval, suggesting that errors are distributed in accordance with task-load. This was demonstrated statistically in the Phase I study (Ref. 1) where similar data for switching were compared using the Kolmogogorov-Smirnov Test (Ref. 6). No consistent results were obtained supporting the hypothesis that switching error frequency is indeed proportional to the number of switches activated.

However, it can be seen also from Fig. 6 that the increase in errors is greater than the increase in operations following the relatively inactive intervals (note mission time intervals 48 hours to 72 hours and 144 hours to 168 hours, which are both coast periods), supporting the Phase I conclusion that constant work-load may be a more desirable characteristic than minimal work-load.

In summary, the analyses performed indiated that only oral temperature and pulse rate may have been affected by diurnal cycle variation. Blood pressure, isometric performance, and switching performance data demonstrated no effect as a function of the change in routine. Furthermore, no adaptation to the duty cycle was apparent over mission time. In spite of this switching performance was demonstrated to be consistently high during the entire mission, and reducduction in mission load-displaced on mission isometrics was determined to be a function of reduced volume, food intake and generally sedentary activity.

6. Mission to Baseline Correlates

In Phase I, differences between systems, phases, systems by phase interaction, etc. were tested for significant differences for both switching and flight control data. No consistencies were developed, however, certain crews performed differently on certain isolated phases. Furthermore, Section 4 indicated significant differences between phases when raw error scores were compared. The error scores represented average deflection from a nominal attitudinal flight path.

This difference existed in both baseline and mission data. Because of possible differences in phases, it was of interest to examine both baseline and mission performance to determine if they varied in the same way across phases.

A. Method

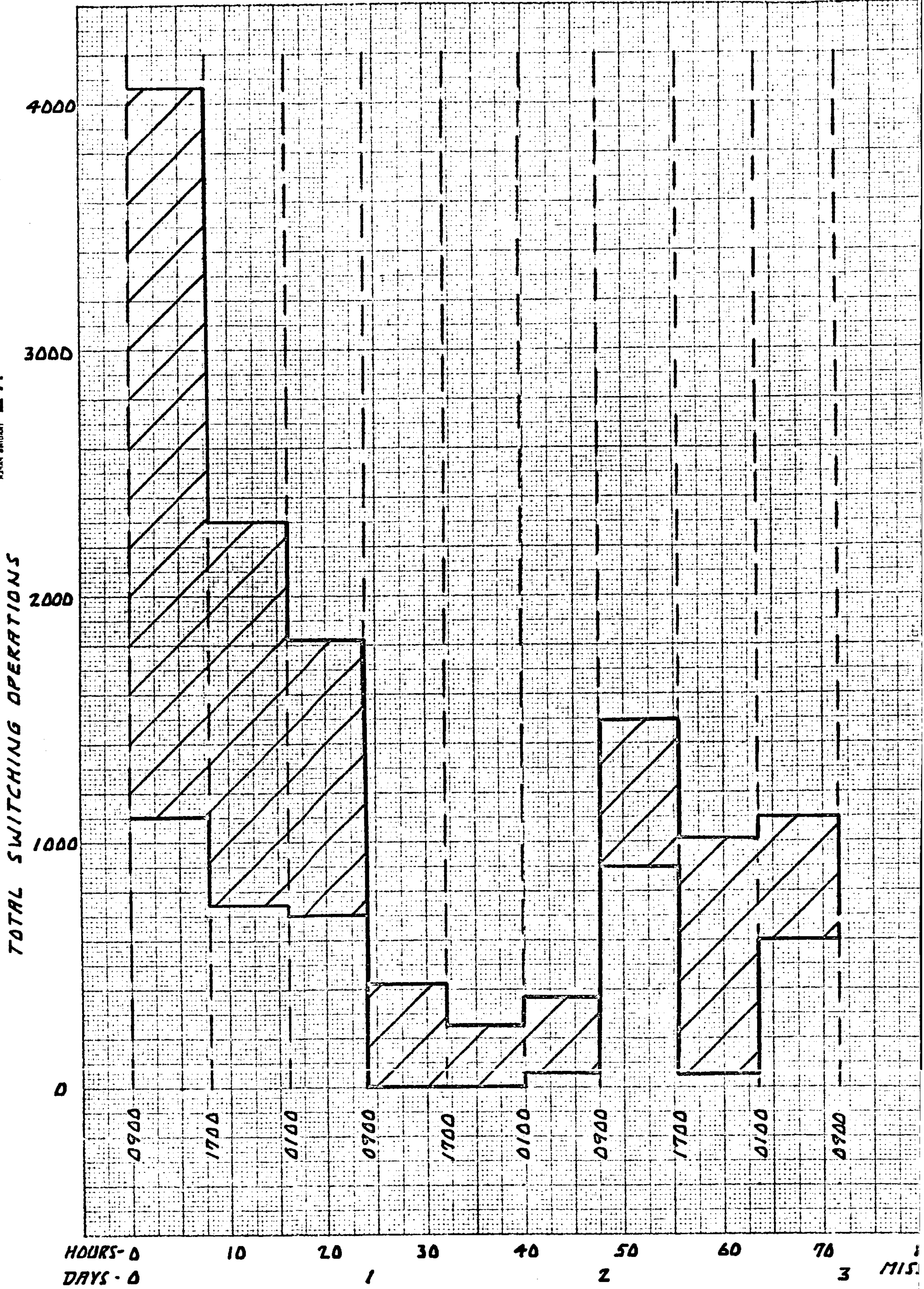
Two separate types of data; switching and flight control, were subjected to statistical analyses for each crew individually, and for all crews combined.

Reliability for baseline (R_B) and mission (R_M) were ranked and correlated using a Spearman Rank-Order Correlation (Ref. 7).

B. Results

(1) Switching - The result of the switching performance analysis is illustrated in Table 29.

64A-1


TOTAL SWITCHING OPERATIONS
4000
3000
2000
1000
0
0900
1700
0100
0900
1700
0100
0900
1700
0100
0900
HOURS- 0
10
20
30
40
50
60
70
DAYS - 0
1
2
3
MIS

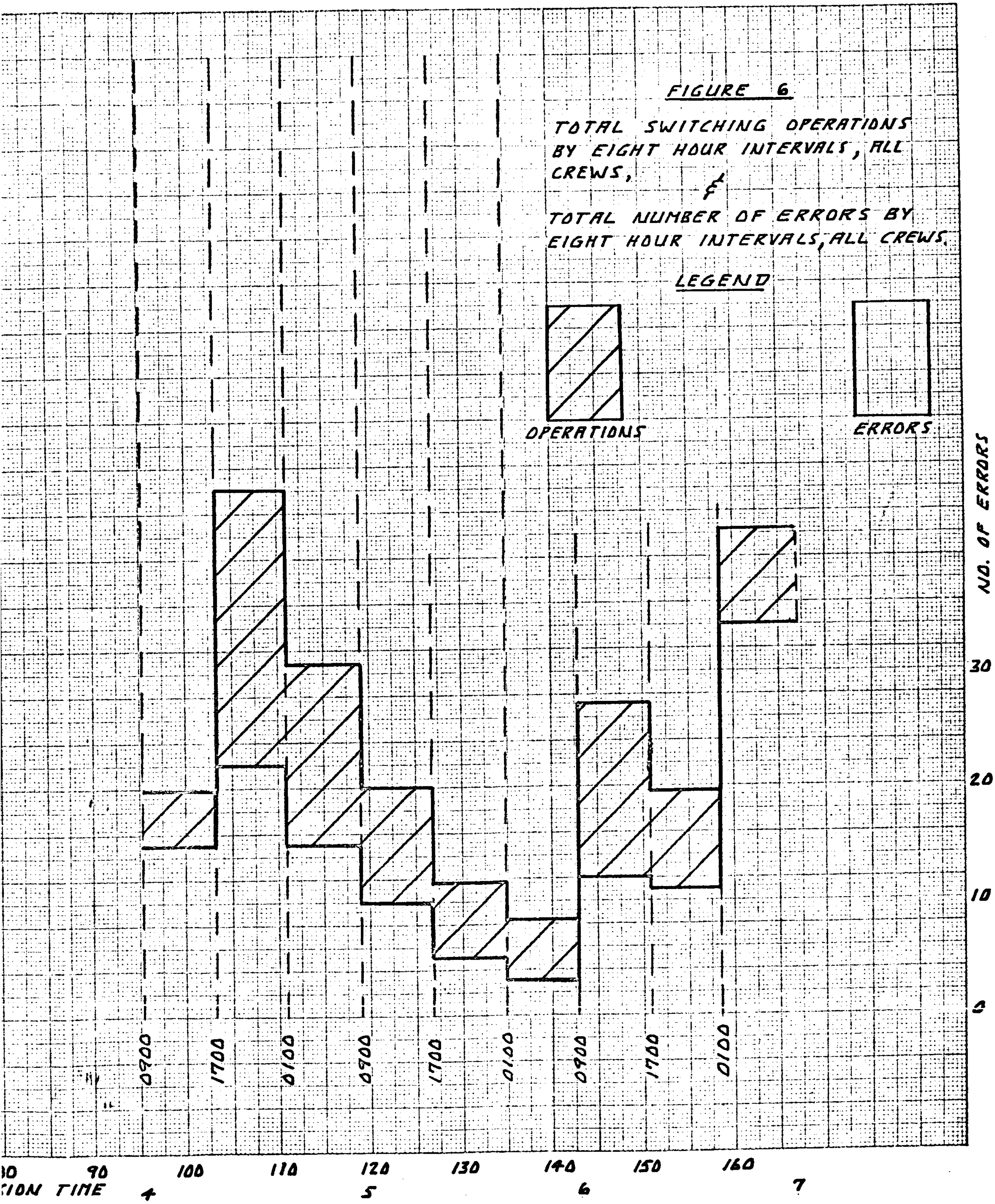


FIGURE 6

TOTAL SWITCHING OPERATIONS BY EIGHT HOUR INTERVALS, ALL CREWS, & TOTAL NUMBER OF ERRORS BY EIGHT HOUR INTERVALS, ALL CREWS.

TABLE 29

Values of r_S for Switching Baseline by Mission Switching Performance

Crew	r_S
I	-.048
II	.4515
III	.5273
IV	.6136*
V	.8068**
All	.6818*

*Significant at .05 level
**Significant at .01 level

As can be seen from the switching correlations, Crews IV and V, and all crews combined showed significant positive correlations between mission and baseline performance.

Since Crews IV and V had consistent, extremely high mission and baseline switching performance, the performance variability was quite low. With low variability a significant r_S is almost assured, and the resultant correlation cannot be validated. It is believed, however, that the data for all crews combined is a reasonable representation of an existing positive correlation, and as the differences between crew performance level exists in both mission and baseline, it provides a reasonable index of the baseline performance of all pilots relative to mission.

The significant correlation in the positive direction indicates that, since performance was ranked from low to high, pilots tend to do worse during those mission phases that exhibited lower performance during baseline.

(2) Flight Control

Table 30 illustrates the results of the correlation tests performed between baseline and mission flight control reliability.

TABLE 30

Values r_S for Flight Control Baseline by Mission Flight Control Performance

Crew	r_S
I	.557
II	.257
III	-0.300
IV	.133
V	1.000**
All	.064

*Significant at .05 level
**Significant at .01 level

As can be seen only crew V showed any significant results. This crew demonstrated perfect (1.000 Reliability) performance in four of the six mission phases in both baseline and mission, therefore, there was very little variability in Crew V performance, and the significant correlation is meaningless, particularly since the trend was not demonstrated for any other crew.

It was also desirable to analyze mission-to-baseline correlates with differences in phase complexity controlled. To accomplish this, the mission was normalized by the appropriate phase baseline levels as in Section 4 (Equation 3).

A Spearman Rank Order Correlation, similar to that described above, was performed on baseline reliability compared to normalized reliability (Equation 7). The results are indicated in Table 31.

TABLE 31

Values of r_S for flight control baseline by Normalized Flight Control Performance

Crew	r_S
I	-.0857
II	-.1857
III	-.614
IV	-.6857
V	1.00**
All	-.614

*Significant at .05 level
**Significant at .01 level

Once again, only Crew V demonstrates a statistically significant correlation, and this is most likely due to lack of variability in both baseline and normalized reliability scores. Since Crew V had reliability of 1.000 on four phases in both baseline and mission, the normalized reliability remained at 1.000 for those phases and the distribution of rankings remained unchanged.

For the statistic employed, only six phases were available. With such a small number of data points, the requisite r_S must be quite high before it is significant ($r_S .01_{(6\ DF)} = .917$), and had the sample (flight control phases) been larger, a significant baseline to mission relationship might have been demonstrated.

What is of greater interest in the normalized data analysis is that all but one of the correlations are in a negative direction suggesting that the crews performed better on those mission phases that exhibited poorer base-line performance. Furthermore, although none were significant, six of the correlations are greater than -.600 with Crews I and II demonstrating negative correlations nearer to zero.

One possible explanation presents itself; over-training may have caused the negative correlations since it was demonstrated in the Phase I study (Ref. 1) that Crews III, IV and V were trained to a higher performance level than Crews I and II.

Another alternative explanation may be that the performance shift in phases was due to the nature of the mission itself. That is, there may have been some behavorial phenomenon that existed in the 7-day mission that could not be identified or controlled in the part-task training situation.

These reaults point to a need for additional study for application to the Apollo training program and mission, as well as other long-duration space systems. In-flight studies would provide excellent means for determining the existence of over-training as well as the validation of the high fidelity simulation techniques for performance assessment. Such an approach is discussed in Section III.

7. Extrapolation to Current CM Configuration

The objective of this effort was to determine which results, findings, and conclusions described in Phase I (Ref. 1) and the presnt report could be directly extrapolated to the current Apollo Command Module configuration. A number of available documents (see Refs. 14-21) containing data on system functions, display/controls and the categories specified for the current CM were reviewed as a first step in this analysis. Additionally, a cursory review of the Apollo Procedures Mockup at NASA-MSC was performed on on 17 October 1966. .

Where data concerning the current CM were unavailable, it was so noted and the extrapolation was developed under the assumption that the CM and simulator were identical.

As indicated in both the previous technical sections of this report and the Phase I study, pilot performance was generally high, with very few consistent trends developed. Furthermore, it was suggested that some of the significant results were the result of simulator artifacts, notably the criticality of flight control errors. However, this fact does not preclude the utility of applying results to the operational CM. Many of the analyses of this study have provided results, which, although not significant, may be indicative of possible operational phenomenon and therefore are worthy of further study and judicious consideration.

Categories reviewed included system functions and crew tasks, display/control relationships and checklist and training. These serve as a basic framework for applying and comparing qualitative, and where possible, quantitative data from the simulated 7-day CM missions to the presently-programmed CM development.

a. System Functions and Crew Tasks

No consistent system effects on switching performance were found following Phase I analyses of either individual system or logical system interactions. Pilot debriefing and mission log comments regarding flight control system effects were chiefly concerned with furnishing more meaningful performance parameters during the Earth Entry phase. The need for duplicating actual flight path, dynamic pressure, gravity load, etc., were especially stressed as important for effective and "realistic" system operation during

Earth Entry. Reference 17 indicates that the EE phase will be automatic with a manual back-up system. In the event of a emergency manual operation, the incorporation of such a flight control display system becomes more meaningful.

Most of the remaining pilot comments concerning systems and tasks were the result of simulator artifacts.

None of the pilot remarks alter the Phase I finding that system function phase and system/phase interaction effects, appear to contribute minimally in terms of any trend in mission errors made by the crews. This is especially noteworthy since the simulated system was very close to the actual system design reviewed, particularly in switching actions between any one subsystem and another, (Refs. 17 and 18).

The Phase I study did conclude, however, that some crew members do less well in some phases than others, although no consistent trends were demonstrated for either flight control or switching tasks. It was hypothesized that as long as the pilots are not overloaded, it is more important to maintain a constant workload than to be concerned with the total magnitude of operations.

These findings agree very highly with pilot opinion in that nearly all pilots believed that they were quite capable of performing all programmed and emergency CM tasks. About half the pilots recommended they be given manual control over the launch or boost phase which terminates in an earth parking orbit during the mission. They are supported in this request by several studies on pilot control of boost phases (Ref. 16) which indicate acceleration profiles, vehicle bending, and fuel sloshing present no problems for the pilot in controlling launch of multi-stage boosters, provided he has an adequate display/control system.

A pilot opinion ranking of CM flight control tasks, showed Earth Entry and Transposition tasks ranked highest in adjudged difficulty (see Table 39, Ref. 1). Earth entry as a whole was considered by one crew member as "a task which required close attention to detail, continuing and sometimes rapid decisions, planning, foresight, different flight profile according to error mades, and the possibility of disastrous results from a small error or moment of inattention."

The pilot opinion of flight control task difficulty was partly confirmed by quantitative data from the Phase I study indicating some degradation in flight control mission performance occurred when compared with baseline performance. That is, flight control errors of a critical nature occurred during the simulated mission; however, these were likely a result of the simulator system and the error criteria. It will be recalled from the Introduction of this report (Section I) that the criteria for a flight control error was that the mission parameter score fall outside the mean plus three sigma level established from the distribution of baseline scores. Thus, the criteria for success were not necessarily similar to the actual system requirements. However, if the actual system constraints require pilot performance close to the mean plus three sigma levels established in training, it is reasonable to expect the occurrence of flight control errors during the mission, some of which may be critical. In order to preclude mission errors either additional training or the reduction in the stringency of requisite flight control performance through system modification should be incorporated.

Another important conclusion reached was that task performance variability did occur during the simulation but with no serious effect on mission success. The possibility remains, however, that increased variability due to task overloading, extension of mission time duration, or additional time-critical activities, could contribute to performance degradation.

b. Display/Control Relationships

Quantitative findings in the area of display/control relationships (Ref. 1) suggested that as long as the crew is neither task overloaded, nor performing time-critical tasks, the Human Engineering design requirements may be reduced. Phase I results also indicated that "a new set of design criteria may be required for space sytems in order to be more commensurate with the pilot skills." Furthermore, comparison with the configuration of Ref. 17, has indicated that many modifications have already been incorporated in the CM.

Table 4 in Section II.1 of this report indicated that all pilots had some negative remarks on the basic panel layouts of displays and controls. These were reflected in constructive criticism and recommendations ranging from setting up effective sequential scan patterns and functional grouping of instruments and switches to improved lighting, elimination of parallex effects on displays, and better switch identification and labeling. The comments concerning display groupings were made in consideration of two phases; Earth Entry and Transposition. One of the most frequent comments in the area of human engineering deficiencies was that "critical" switches were not guarded, locked-out, or separated properly from "non-critical" switch operation. The latter observation, however, does not coincide with Phase I findings that no critical switching errors occurred, and that the majority of switching errors had no direct influence on mission success. Furthermore, most of the critical switches are guareded in the Apollo Procedures Mockup.

A comprehensive etiology of switching errors (based on Tables 1 and 2 and Ref. 5) presented a breakdown of specific and total errors made by each of the five crews. A review of the breakdown by crew was considered necessary in fully exploring display/control relationships and their extrapolation to the current CM, although the Phase I results found no consistent pattern to switching errors either in terms of the mission or switch location.

Analysis of switching performance for Crews IV and V revealed that only seven errors were made by the combined crews with each error on a different switch. Crew III committed only 12 errors, but 4 of these, or 33.3 percent, involved the Uplink Telemetry (or UTEL) switch on the computer. Out of a total of 105 errors for Crew II, 13 percent involved the same UTEL switch above with another 9.5 percent charged to improper operation of a Lamp Test switch for the Caution and Warning System displays. Finally, Crew I was found to have the largest number of errors (117), of which nearly half, or 45.3 percent, involved three tape recorder switches located adjacent to each other. The UTEL switch and the communications panel are relatively similar to the current system (Ref. 17).

Although, as noted earlier, the above switching errors were not considered real hazards to mission success, several recommendations are nonetheless presented for possible application to the present CM configuration, according to Ref. 17, in assuring even more reliable task performance in the Apollo mission.

(1) Redesign the Uplink Telemetry (UTEL) switch and its corresponding Uplink Acitivty indicator (presently associated with a "computer activity indicator") into a combined switch. A trans-illuminated pushbutton switch with appropriately labeled operational terms is suggested in this case.

(However, instead of using the present terms "ACCEPT" and "BLOCK" (Ref. 17) on the proposed switch's two subdivisions, "ACCEPT" and "NO GROUND DATA" might be clearer in the uplink telemetry operation to the pilot. A clear set of procedures will also be of value in preventing potential error.)

(2) Redesign the communications panel in the CM, and particularly, the tape recorder functional group. This can be done, for example, by combining the present tape recorder toggle switches into one rotary switch for all functions, or by separating the "toggles" spatially and/or through improved marking or delineation. The prime factor for the large number of errors made by Crew I on the tape recorder switches was poor checklist information on tape sequences, however, review of the current CM panel indicates (Ref. 17), that it is similar to the CM simulator. It was noted in the Human Engineering Section (Phase I, Section 5) that, should tasks become more time-critical, poor human engineering effects would be more prevalent. Thus, the panel redesign is recommended.

(3) Relocate the RCS switches from Panel 16 to Panel 15, where they will be nearer the RCS helium and propellant switches.

(4) EDS switches are currently located on Panels 16, 24 and 26. They should be located together, preferably nearer the appropriate warning indicators.

(5) There was a parallax problem in interpretation on the FDAl in the simulator. No data are available to indicate that this problem does not exist in the current CM. Back-lighting should be provided.

(6) No data were available concerning the LEM transposition. In the simulated mission, the CSM and LEM were separated and automatic stabilization equipment nulled any angular accelerations of either module. The task was to pitch the CSM 180° and dock the CSM and LEM. Information for this

task was presented to the pilot as displacement in pitch, roll, and yaw. Although unlikely, if such a manual transposition task is performed in the Apollo mission, it is recommended that a closing-rate or displacement rate in three attitudes be provided.

(7) Finally, the documentation available indicates that the Earth Entry phase of the operational mission will be automatically controlled with a manual back-up. The data further indicate that, in the event of a failure in the automatic, the pilot has only the FDAl altimeter, and "angle-of-attack" (a) indicators (Ref. 17 and Procedures Mock-Up). Since any control errors during entry are critical to successful recovery, it is recommended that the following displays be provided for emergency manual re-entry:

(a) Range error

(b) Velocity error

(c) Altitude error

(d) Altitude rate error

(e) Crossrange rate error

(f) Required roll maneuver

It is suggested that these displays be located as near the FDAl as possible, and arranged in a suitable scan-pattern.

Checklist and Training

The following recommendations, derived from the simulator program, are applicable to the Apollo Program:

(a) The checklist should be detailed, consistent in format, provide phase and time references and labels for all critical operations.

(b) In general, the training program for the simulation was found to be adequate. Results of this study indicated that, for flight control, mission performance was better on those phases that exhibited poorer baseline performance. This phenomenon may be due to overtraining, or it may be due to some behavorial phenomenon present only in the mission.

It is suspected by the authors that the shift in relative phase performance between baseline and mission was the result of the added realism, long duration confinement, and other mission phenomena. Whatever the cause, this area requires further study. In-flight study is recommended as one possible technique. This technique would provide a means of validating the integrated mission simulation approach to complex operator assessment, using actual system measures at a minimal cost and weight penalty, and would indicate if such performance perturbations that occurred in the simulated mission could indeed be expected in an operational situation. The validation study would define the systems measures, skills, telemetry, and maneuvers required for the operational system. Part- and whole-task simulation data would then be compared with operational system measures.

If the operational mission performance levels are similar to those obtained from the ground-based simulations, the high-fidelity whole-mission simulation technique will have been proven to be a much more valid predictive measure of complex operator performance than part-task techniques, including those with high face validity.

(c) The most meaningful training result obtained was the value of daily feedback of performance results. By keeping the pilots abreast of their errors, they were quickly able to assimilate and alleivate the sources. The advisability of such an approach was demonstrated by the differences in all phases of performance between those crews that had the benefit of feedback, and those who did not.

(d) The training program was scheduled to preclude mass practice effects with the maximum number of repetitions dependent on the complexities of the phase involved. The training schedule was modified weekly in order to provide training in those phases where practice was most required. These approaches to a training program were found to be highly effective in preparation for the mission, and should be incorporated into the Apollo Astronaut Training program.

(e) During the fourth week of the training program, a two-day integrated fast-time mission was conducted. This served to familiarize the crew with the details and peculiarities of the mission and to provide some adaptation relative to the living requirements within the simulator. The fast-time mission consists of each crew member performing each phase in mission sequence under typical mission conditions, except that all coast phases (earth parking orbit, translunar coast, lunar coast descent, lunar coast ascent, and transearth coast) were abbreviated to meet the time required to perform the necessary piloting and switching tasks. The fast-time mission concept was utilized during the training of all crews, and was considered highly effective. It is a recommended technique for incorporation into the Apollo Training program.

In conclusion, it must be re-emphasized that, in general, pilot performance was consistently high during all mission phases, consequently trends were very difficult to identify. Some of the recommendations of this section may become increasingly important during periods of high activity or stress, or for longer duration missions.

Finally, some of the errors that occurred, notably flight control and CM, were likely a function of the simulator system or performance criteria, and, as such, are only capable of extrapolation to theCM if similar constraints are operating in the operational system.

III. MAJOR CONCLUSIONS

The analytical methods, results and general conclusions are detailed in Section II of this report. Replicated here are those conclusions most germane to the Apollo CM.

A. Pilot comments generally agreed with their rankings of the displays and controls. Transposition and earth entry were deemed the most difficult flight control phases and this is supported by the data.

B. The checklist was considered to be adequate with 17% of all switching errors attributable to the document. Nearly all of these (37 of 41) occurred in Crews I and II as a function of omitted steps. Generally, it was recommended that the Apollo checklist have a consistent format, time and phase references, and some identification of critical tasks.

C. No deleterious effects on performance were noted as a result of communication black-out periods.

D. Although operationally nearly identical, some phenomenon caused attitude control performance in LOI to be consistently worser than the other insertions. This occurred in baseline, mission, and normalized data analyses. Furthermore, the Earth entry phase control performance was consistently more variable than the insertions. It was concluded that there may be a performance change caused by changing spacecraft inertia, however, these effects, if they exist, were confounded by other variables, such as mission time effects. The changes in attitude control performance were all within the error criteria.

E. There was no correlation between mission exercise performance and switching performance, or mission exercise performance and any of the biomedical parameters monitored.

F. There was an indication, albeit inconclusive, of a diurnal cycle effect on temperature and pulse rates, with low points occurring in the early morning hours. There was no such effect demonstrated for other physiological parameters, switching performance or exercise performance, nor were there any demonstrable adjustments to the work-rest cycle over the seven-day mission.

G. Mission switching performance was generally higher on those phases that exhibited higher baseline performance, However, normalized flight control results indicated that higher mission performance was demonstrated on those phases that exhibited lower baseline performance. No conclusive reason for this was determined, but over-training may be related. Another and more probable explanation was the suggestion that the integrated mission simulation provided a more reasonable prediction of performance than did the part-task technique utilized in baseline data collection. It was suggested that in-flight studies be performed in order to provide measures of the relative validity of performance assessment techniques.

H. A number of detailed changes in the operational system were suggested on the basis of the study and available documentation. Among these recommendations were the relocation of particular switches and the inclusion of some information displays, as well as a suggestion for inclusion of daily performance feedback during training.

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